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ABSTRACT

This document describes Texas' natural resources and suggests ways to correlate conservation instruction into the existing curriculum. Resources discussed include: 1) soil (soil formation; properties of soils; soil survey, soil use in agriculture; soils and the state economy, land value; specific soil resources); 2) air (principal pollutants and their effects; methods of detecting and measuring air contaminants; methods of eliminating/reducing air contaminants; automobile exhaust emissions; legislation and control agencies; air control regions/programs); 3) forests (forests serving people; tree regions; commercial forests and industry); 4) wildlife (game mammals and birds; food/game fish; non-game animals; rare/endangered species; government roles in wildlife management; economic value of Texas wildlife); 5) rangeland (importance and historical use of rangeland; climate; soil formations; managing rangeland resources; physiological aspects of range plants; ecological considerations; range condition classification and improvement practices); 6) mineral (mineral production and economy; distribution of mineral resources; mineral industries); 7) oil and gas (search for oil and gas; exploring for oil; crude oil production; energy shortage; federal/state regulation; natural gas production; refining and petrochemicals; transportation; marketing; oil/gas reserves); 8) water (general considerations, specific water resources; planned/developmental agencies; priorities for use of water; state/national economy); and 10) estuarine resources (general characteristics and estuarine life). (JN)

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Foreword

Nature has richly endowed Texas with a variety of natural resources that, by wise use and progressive management, can be developed to their maximum utilization. However, rapidly expanding population and technology place great demands on these resources and may result in pollution and danger to human and animal life as well as to the environment.

Environmental Education: A Guide to Teaching Conservation in Texas describes the state's most important natural resources—soil, air, water, forests, wildlife, rangeland, mineral, estuarine, oil and gas—and suggests ways to correlate conservation instruction in the existing curriculum. The *Guide,* a revision of the 1972 Texas Education Agency Bulletin 709 *Environmental Education: A Guide to Teaching Conservation in Texas,* contains updated material on environmental concerns. It includes new chapters on the state's estuarine resources and on oil and gas resources.

The publication is provided to assist Texas schools to develop in children and youth an awareness of and an appreciation for the natural resources of the state and nation. The hope is that, as future citizens, students will be motivated to use our resources wisely and to support intelligent management of them.

Alton O. Bowen
Commissioner of Education

Acknowledgments

This publication was developed with the assistance of the Texas Advisory Committee on Energy and Environmental Education which was appointed by the State Board of Education to advise the commissioner of education and the Texas Education Agency on energy and environmental education. Functioning in an advisory capacity, the Committee offers suggestions, provides advice and counsel on ideas and materials being developed, and promotes program activities.

Instrumental to the development of the *Guide* were the following agencies, members of a resource group to the Advisory Committee:

U.S. Soil and Conservation Service
Texas Parks and Wildlife Department
Bureau of Economic Geology
Texas Forest Service
Department of Water Resources
Texas Air Control Board
Texas Mid-Continent Oil and Gas Association

Additional assistance was provided by the Texas Agricultural Experiment Station and the Texas Agricultural Extension Service of Texas A&M University System.

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Soil Resources of Texas

Soils represent one of the most valuable resources of the state, a resource that is becoming more and more valuable as demands on land increase. Soils are vital for the production of food, forage, trees, and fiber and for development related to industry, recreation, housing, and transportation.

Currently there is an increased interest in the nature of soils due to a growing need to learn about their suitabilities and behaviors for urban uses. Urban uses are those not directly related to the production of food, fiber, feed, and timber products.

Farmers and ranchers have long recognized differences in the behavior of soils. Other persons also are recognizing that some soils are better than others for certain uses. Soils that are suited for one use may not be suited for another. Exploitation of soils for uses for which they are not adapted can result in costly mistakes. Problems often develop because persons don't realize that soils have different potentials for different uses.

SOIL FORMATION

Soil is the product of its environment. It forms at the earth's surface as atmosphere, sunlight, water, and living organisms meet and interact with minerals. There are five major soil-forming factors; all interrelated in nature. These factors are: 1) climate, 2) living organisms (plant and animal life), 3) parent materials (geologic deposits), 4) topography, and 5) time. Soils vary from place to place as the soil-forming factors change. Because the soil-forming factors in Texas are so highly varied, many different kinds of soils exist within the state. A discussion of each of the soil-forming factors follows.

Climate

Temperature, rainfall, and humidity govern rates of weathering of rocks and parent materials and the decomposition of minerals. Thus, climate functions directly in the formation of soils. Also, it has an indirect effect through control over the kinds of plants and animals that can thrive in a region.

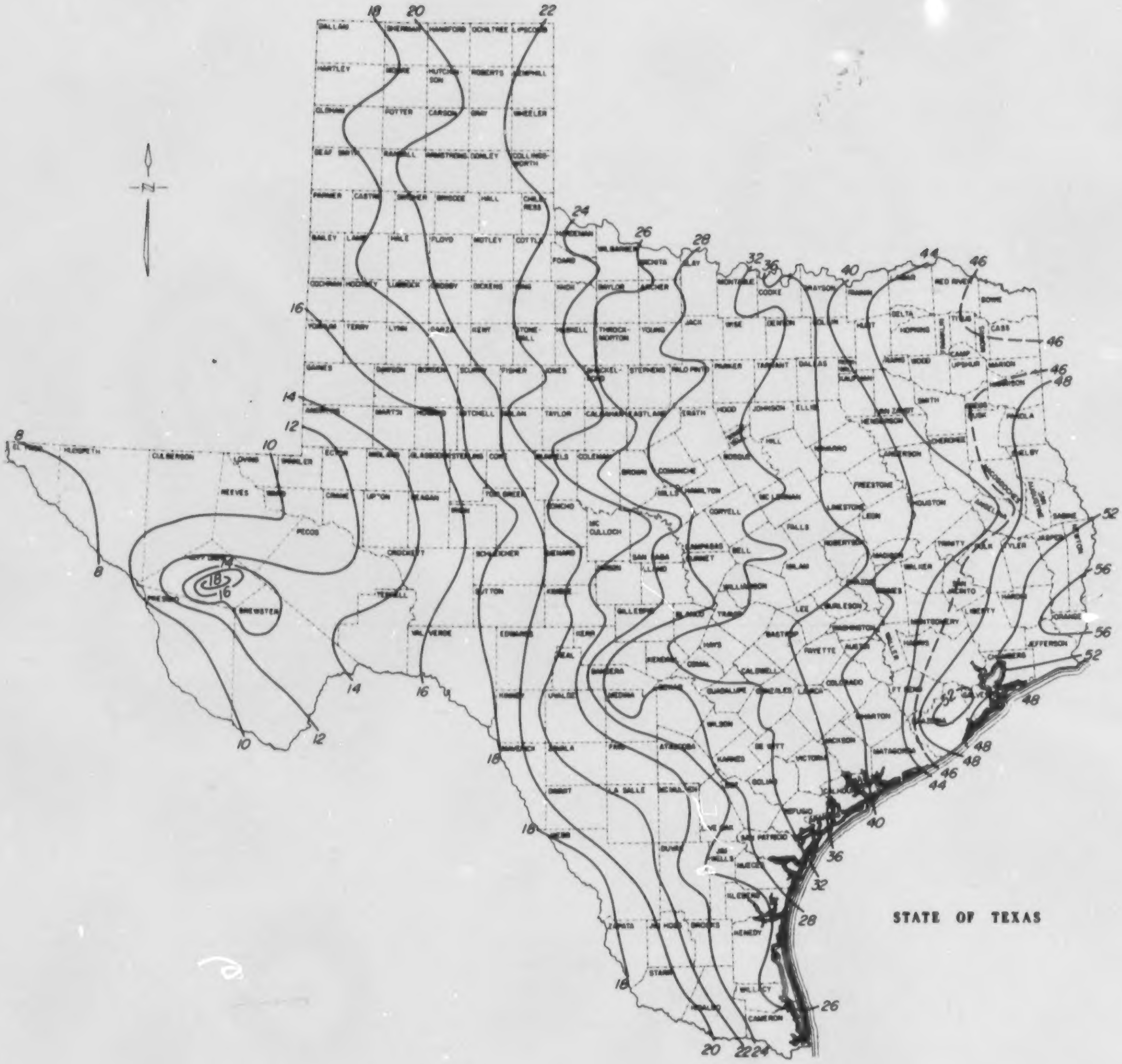
The Texas climate varies from humid to arid and from temperate to subtropical. Various regions of the state are subject to sudden changes in the weather and to occasional hail, torrential rains with flooding, tornadoes, freezes, hurricanes, and droughts. Sunshine is also abundant, ranging across the state from the east to west from about 60 to 80 percent of the time. Relative humidity (east to west) at 6 p.m. commonly ranges from about 70 percent to less than 30 percent.

Average annual rainfall ranges from more than 50 inches in the humid Timberlands of southeast Texas to less than 10 inches in the arid parts of far west Texas.

Average annual rainfall varies from year to year and over periods of several years. Figure 1 illustrates the mean annual rainfall in Texas. Rainfall is highest over much of the state in the spring months, especially in May. In the Trans-Pecos area, July, August, and September are major months of precipitation. Average precipitation exceeds average evaporation only in the eastern part of the state.

Mean annual temperatures range from about 56°F in the Northern High Plains to 74°F in the Lower Rio Grande Valley. An average frost-free period ranges from about 180 days to over 230 days from north to south.

Temperature and humidity affect evaporation. Much of Texas has warm temperature and low relative humidity a large part of the year. Drouths are common in nearly every part of Texas, especially in the summer; however, their severity and duration vary yearly and over periods of years.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STATE OF TEXAS
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Figure 1. MEAN ANNUAL RAINFALL (IN INCHES) IN TEXAS

Living Organisms

Living organisms such as plants, animals, earthworms, and micro-organisms, along with climate, are the active factors of soil formation.

Under each climatic regime, a certain type of mixture of vegetation will establish itself. Due to the varied climatic regimes in Texas, a variety of grasses, shrubs, and trees exists. This vegetation, in turn, influences the development of the soil.

The influence of vegetation on characteristics of the soil is illustrated by a comparison of soils across the state. The soils that have formed under a cover of trees in the eastern part of the state have properties distinctly different from the prairie soils common to the central part or the desert soils in the far western part. Differences are mainly in the amount of leaching; kinds, amounts, and distribution of organic matter and nitrogen; gains or losses in plant nutrients; and structure and porosity.

Micro-organisms live mainly on plant and animal residues and are responsible for the breakdown and decay of organic residue into humus. Burrowing animals, along with plants, may mix layers of soil and retard differentiation.

Parent Materials

From the shores of the Gulf of Mexico to the mountains and plains of West Texas, an array of landforms and outcrops of rock formations indicates that a complex history of uplifts, volcanic activity, invasion by seas, and erosion by wind and water have influenced the shaping of the Texas landscape. Also influenced have been the deposition and exposure of sediments associated with various geologic periods. Figure 2 shows a general picture of the geological formations of present surface exposures in Texas, along with elevations.

In the Central Basin, granites, gneisses, and schists (three billion to 600 millions years old) are mixed with younger sandstones and limestones (600 to 400 million years old).

In the Trans-Pecos area, shales, limestones, sandstones (600 to 400 million years old), and outwash from these formations comprise present sediments for the soils.

Sedimentary rocks, deposited around 345 to 280 million years ago, are parent materials for soils in the North Central Prairies.

Clayey and sandy red beds and limestones, deposited around 280 to 230 million years ago, are parent materials for most of the soils of the Rolling Plains. At the western extent of the Rolling Plains, immediately east of and below the Cap Rock Escarpment, younger sedimentary rocks, outcrop. These rocks consist of shales, sandstones, and limestones and were deposited about 230 to 180 million years ago. In the southern part of the Rolling Plains, outwash from limestones and limy earths have influenced the soils. The assortment of parent materials gives rise to soils varying widely in their properties.

Chalk rocks deposited around 135 to 63 million years ago are extensively exposed in Texas. In the Edwards Plateau, Grand Prairie, and portions of the Trans-Pecos, sedimentary rocks, consisting mainly of limestones, chalk, and limy earths, are parent materials for extensive areas of soil that are mostly shallow to moderately deep.

In the West Cross Timbers, soils have formed in sediments derived from sandstones and shales of Lower Cretaceous age. Sandstones and shales are parent materials for similar soils in the East Cross Timbers.

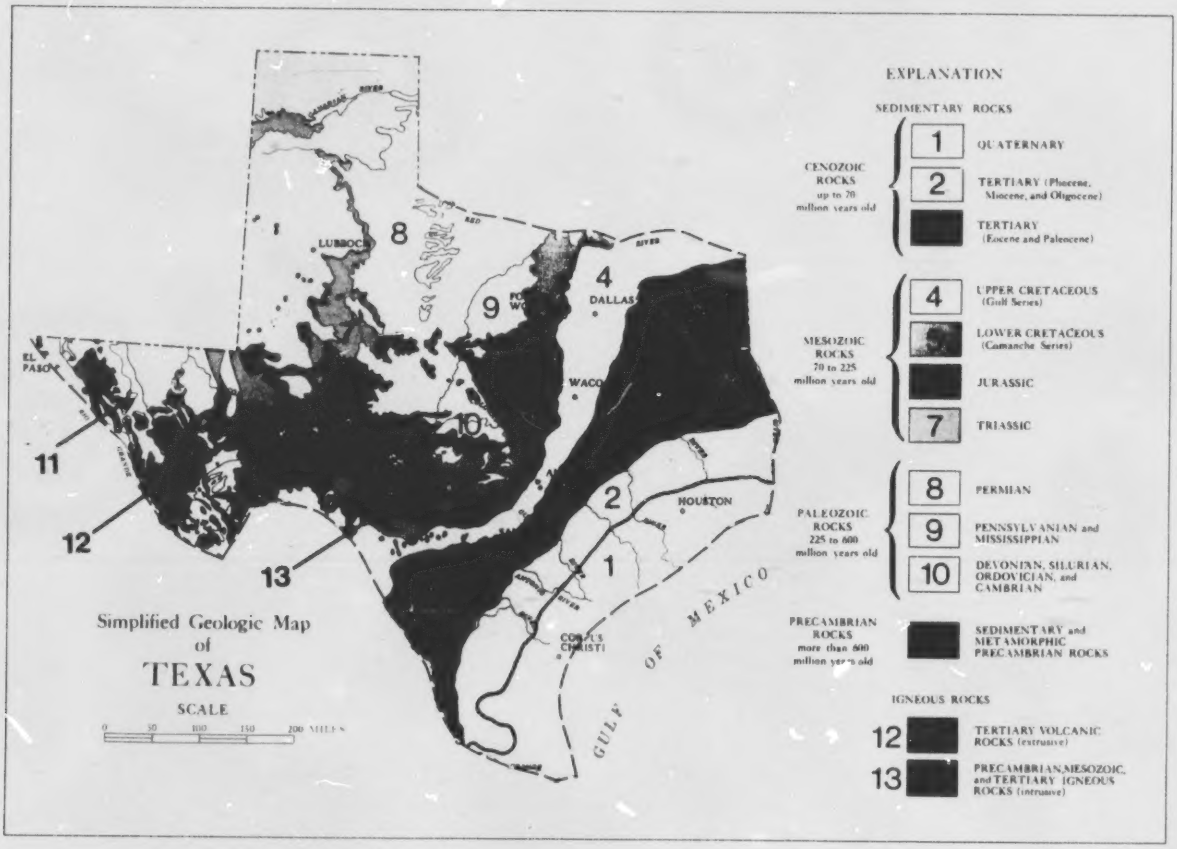

Simplified Geologic Map of TEXAS
SCALE
0 50 100 150 200 MILES
EL PASO
LUBBOCK
DALLAS
WACO
HOUSTON
CORPUS CHRISTI
GULF OF MEXICO
1
2
4
8
9
10
11
12
13
EXPLANATION
SEDIMENTARY ROCKS
CENOZOIC ROCKS up to 70 million years old
1 QUATERNARY
2 TERTIARY (Pliocene, Miocene, and Oligocene)
TERTIARY (Eocene and Paleocene)
MESOZOIC ROCKS 70 to 225 million years old
4 UPPER CRETACEOUS (Gulf Series)
LOWER CRETACEOUS (Comanche Series)
JURASSIC
7 TRIASSIC
PALEOZOIC ROCKS 225 to 600 million years old
8 PERMIAN
9 PENNSYLVANIAN and MISSISSIPPIAN
10 DEVONIAN, SILURIAN, ORDOVICIAN, and CAMBRIAN
PRECAMBRIAN ROCKS more than 600 million years old
SEDIMENTARY and METAMORPHIC PRECAMBRIAN ROCKS
IGNEOUS ROCKS
12 TERTIARY VOLCANIC ROCKS (extrusive)
13 PRECAMBRIAN, MESOZOIC, and TERTIARY IGNEOUS ROCKS (intrusive)

Figure 2. GEOLOGIC FORMATIONS OF TEXAS

Formations consisting of chalks, shales, marls, and calcareous clays are parent materials for the soils of the major portion of the Blackland Prairies and for some of the soils in the northwestern part of the Rio Grande Plain. In the Blackland Prairies and in places in the Rio Grande Plain, calcareous clayey formations provide parent materials for soils similar to those in the Blackland Prairies.

Sedimentary rocks outcrop extensively in the eastern one-third of Texas and in the High Plains and Trans-Pecos areas of West Texas. In the eastern part of Texas, sediments were deposited by fluvial, deltaic, and marine processes related to the ancestral Gulf of Mexico. Soils of the East Texas Timberlands, the Claypan Area, and much of the Rio Grande Plains have formed in stratified clayey and sandy deposits.

Sandy to clayey sediments (12 million to a few thousand years old), deposited and reworked by both wind and water, mantle the High Plains. These deposits were outwashed from the Rocky Mountain systems. Also, wind-laid sands and loess (silts and clays) blanket much of the High Plains. In the central Rolling Plains, loamy to gravelly deposits from the High Plains mantle many of the broad valleys.

Along the Gulf of Mexico and inland for about 50 to 80 miles is a strip of deposits laid down during the last two million years. These deposits mantle the Coast Prairie and the eastern part of the Rio Grande Plain. They are deltaic and lagoonal clayey and loamy deposits derived from older rocks to the west. At the western edge of the Coast Prairie, the sediments are older, more weathered, and contain more sands.

At the eastern fringe of the Coast Prairie and in the Coast Marsh, soils are derived from deposits that are about 5,000 years old. At the western extreme of Texas, some broad valleys and bolsons are mantled with outwash sediments.

The most recent materials are the parent sediments for the alluvial soils of flood plains. Such soils strongly reflect the source beds outcropping in the headwaters and along streams.

Sediments forming soils along the Canadian River are largely from the High Plains of Texas and New Mexico. Soils along the Red, Brazos, and Colorado Rivers are forming from material largely from Permian red beds. Soils in the flood plains of the Sulphur, Trinity, Navasota, Guadalupe, San Antonio, and Nueces Rivers show the influence of limestones and limy earth deposits. Soils along the Rio Grande and its major tributaries show the influence of relatively unweathered sediments from the Rocky Mountains and Mexico.

Adjacent to flood plains are soils formed on terraces (old flood plains above the present flood plain). Sediments in which the soils of terraces have formed are highly variable but reflect the source load of the stream at the time of deposition. The soils usually are strongly contrasting in their properties relative to the soils in the adjacent modern flood plains.

Topography

Topography influences the formation of soils through its effect on drainage, runoff, and erosion. Along the Gulf coast, in the Rio Grande Plain, and on the High Plains, extensive areas of nearly level soils occur. These are stable landscapes with only slight evidence of dissection. The Trans-Pecos area exhibits a pattern of steep to broken, rough, stony lands interspersed with smooth valleys typical of mountainous areas. The remainder of the state generally has an undulating to hilly topography with well-defined stream patterns and drainage systems (Figure 3).

In most areas of the state, relief has had an influence on soil profile development. The effects of water on soil development are partially controlled by shape, gradient, length, and exposure of slope. Soils on steep slopes will generally be thinner and show less development than soils on gentle slopes because they loose more water to runoff and are more susceptible to erosion. Soils occurring on low flat and concave topography will show the influence of extra water, and in some cases depositions of materials. In areas of higher rainfall, soils in low positions often have inadequate drainage. In drier parts of the state, soils in low positions are usually darker in color, higher in organic matter, and more productive because of the extra water they recei

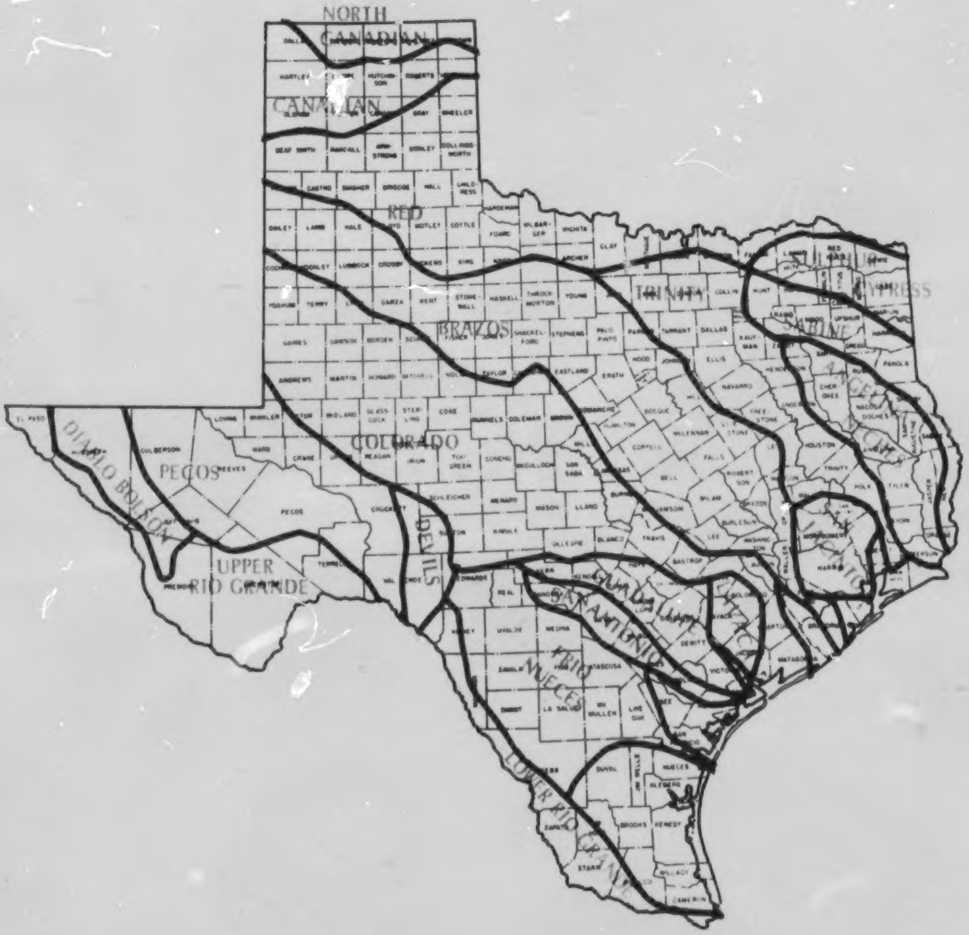

NORTH CANADIAN
CANADIAN
RED
SULPHUR
CYPRESS
TRINITY
SABINE
BRAZOS
NECHES
COLORADO
PECOS
DIABLO BOLSON
UPPER RIO GRANDE
DEVILS
GUADALUPE
SAN ANTONIO
LAVACA
SAN JACINTO
FRIO
NUECES
LOWER RIO GRANDE

Figure 3. PRINCIPAL RIVER BASINS OF TEXAS

Time

Generally, thousands of years are required for the formation of well developed soils. The length of time that soil material has been in place will be reflected in the extent of development of the soil profile.

There is also much variation in the time required to develop soils in different kinds of parent materials. For example, it takes much longer to develop a soil in bedrock, such as limestone or sandstone, than it would in windblown (loess) or water-lain (alluvium) materials.

PROPERTIES OF SOILS

Soils are natural formations on the surface of the earth. They are three-dimensional and have depth, shape, and boundaries. Soils are surrounded by the atmosphere above and the material that is not soil below.

Soil serves as a storehouse for plant nutrients, an anchorage and medium for plant growth, a reservoir to hold water, and a habitat for a variety of living organisms. Most of the organic wastes of nature are decomposed within soils.

Soils are made up of a porous mixture of mineral particles, decaying organic matter, air, and water. Some important properties of soils are texture, structure, reaction, and depth. These and other properties are used as bases for identifying, separating, and classifying the soils. The properties are also important in predicting behavior of soil for various uses.

Texture

Texture refers to the proportional amounts of the different sized particles in the soil. Sizes of soil are designated as clay, silt, and sand. Clay particles are the smallest and sand the largest. Rarely does a soil consist of only one particle size, but rather it is a mixture of all three sizes in varying amounts. Fragments that are coarser than two millimeters in size are referred to as gravel, cobbles, or stones.

Texture is closely associated with fertility, permeability, erosion susceptibility, and tilth of the soil.

Structure

Soil structure refers to the manner in which soil particles are arranged in groups or aggregates. Aggregates differ in size, shape, and stability and in adhesion to one another. The four main kinds of structure are: granular, platy, blocky, and prismatic. These descriptive terms give an indication of the approximate shape that can be expected. Also, some soils are structureless and can be either single grained (loose sands) or massive (clays).

Structure influences the rate at which water and air enter and move through the soil. It also affects plant root growth. Soils having well-developed structure also have favorable plant-soil-water relationships.

Reaction

Soil reaction refers to the acidity or alkalinity of a soil. The common method of indicating soil reaction is by the use of pH values. Pure distilled water has a pH of seven and is designated as neutral. Soils with lower pH values are considered acid and those with higher pH values are considered alkaline or basic.

Soils in the eastern part of the state are generally neutral to acid and those in the western part are neutral to alkaline. Soils that are near neutral in reaction are desirable for most plant growth.

Depth

Soil depth refers to the depth of the soil above bedrock or some restrictive layer, or the depth at which plant roots can penetrate. Soils in Texas are quite variable in depth, ranging from only a few inches to many feet. Soils less than 10 inches thick are considered very shallow; those 10 to 20 inches thick are shallow; those 20 to 40 inches thick are moderately deep; and those over 40 inches thick are classified as deep. Depth of the soil has an important influence on the amount of water the soil can hold. It also influences the kinds of plants and amounts of vegetation the soil can support.

Profile of Soil

Very few properties of soil can be determined from observing the surface. The horizons, or layers, must be studied to determine the nature of the soil. When a vertical section is examined closely, horizontal layering can be observed. Such a section of soil is called a *profile,* and the individual layers are referred to as *horizons.*

The upper layer is called surface soil or surface layer (Figure 4). This part of the soil is in contact with the atmosphere, and weathering is more rapid. Also, the organic matter content is usually greater in this layer. The subsurface layers are referred to as the subsoil. The parent material or bedrock below the subsoil is called the substratum. All the layers above the parent material or substratum are collectively referred to as the solum.

The Soil Series

A soil series is composed of soils that:

- are similar in kind, sequence, thickness, and arrangement of horizons
- are similar in physical, chemical, and mineralogical properties
- generally occur in mappable areas
- respond to similar management and use

Soil series are usually given local geographic names to facilitate soil mapping and communications. An example is the Abilene Series. In Texas there are more than 800 different soil series identified. Each of these has a unique combination of properties and potentials.

Soil series are subdivided into phases based on characteristics that are significant to the use and management of soils. Surface texture varies more than the other properties within a soil series. One or more textural and slope phases may be used in identifying a series; for example, Abilene clay loam, 0-1 percent slope, is a soil phase. A map unit is a delineated area on a soil map with defined composition of soil phases.

THE SOIL SURVEY

A soil survey is an inventory of soil resources in a given area made by field and laboratory examination of the soils. The product is a soil map showing the different kinds of soils in the landscape. The objective of soil sureys is for evaluating and making confident predictions about the soils' behavior in reference to agriculture, soil and water conservation, rural and urban planning, waste disposal, pollution, transportation, recreation, and other uses.

Leadership in the soil survey is the responsibility of the United States Department of Agriculture, Soil Conservation Service, with cooperative assistance from the agricultural experiment stations and land grant universities. The long-range goal of the soil survey is to map and

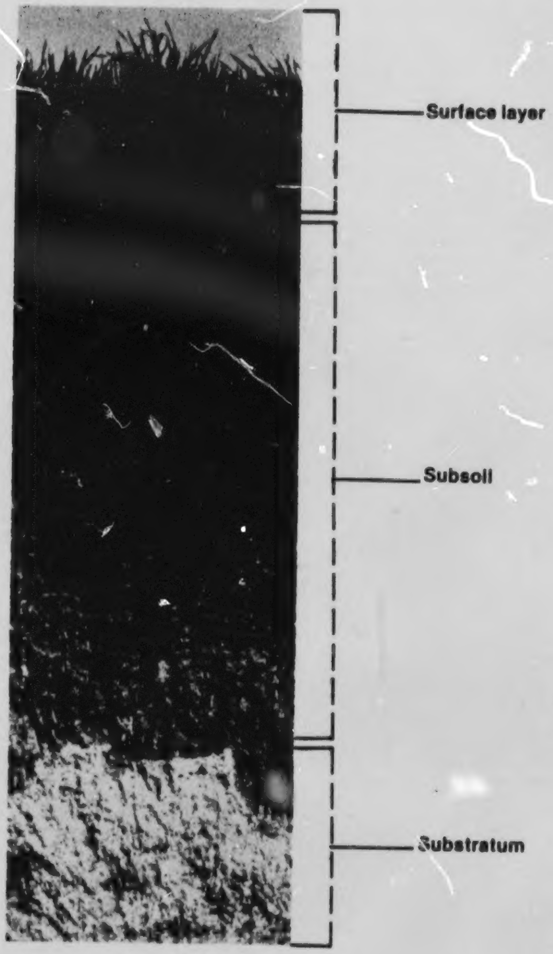

Surface layer
Subsoil
Substratum

Figure 4. A SOIL PROFILE. Organic matter is highest in the surface layer, gradually decreasing with depth. The subsoil gradually merges into the substratum. The layers above the substratum are collectively referred to as the solum.

make available soil maps and interpretative information about the soils for every acre of land in the state and in the nation. Soil surveys have been published for approximately one-third of the counties in Texas. Mapping is complete for a number of others, and these will soon be published. Mapping is in progress in other counties. Also, generalized soil maps are available for all counties.

USE OF TEXAS SOILS IN AGRICULTURE

Maximum utilization of soil resources for agricultural production is rarely obtained. Climatic conditions, supply of plant nutrients, salinity, and physical condition of the soil are the factors most often limiting the productivity of Texas soils. Climate cannot be controlled, but some of the effects of climate can be modified. Selection of plant species, conservation practices, and irrigation and management practices designed to improve efficiency of water utilization are measures that may be employed to modify some undesirable climatic conditions. Plant nutrient supply can be improved by the use of fertilizers where needed, or by growing soil-improving crops such as legumes. Physical conditions of soil can be improved by choice of cropping systems or specialized measures such as mulching or chiseling.

A great deal of progress is being made in improving the utilization of soil resources. The rate of improvement is accelerating in Texas, as well as in other states, and it is reasonable to expect that Texas will become increasingly efficient in the use of soil resources. However, the particular combinations of soil and climate that exist in Texas present a challenge to agricultural workers. At the same time, soil resources represent an opportunity for great improvements in productivity through more efficient use of soil and climatic advantages, increased use of conservation practices, and diligent application of the results of a vigorous, well-rounded research program. A discussion of major problems affecting the use of Texas soils in agriculture follows.

Water

Water is one of the most important factors limiting the productivity of Texas soils. The major part of Texas either receives too little precipitation or precipitation is inadequately distributed through the growing season. As a result, irrigation where water is available is an important part of Texas agriculture. (See Figure 5.) The major problems associated with irrigation are salinity, efficiency of water use, permeability of the soil, interaction of soil fertility level and water supply, and maintenance of desirable physical properties of soil under the more intensive farming operations.

Dryland farming is—and will likely continue to be—the most extensive type of farming in Texas on an acreage basis. It is important in all areas of the state, except in the Trans-Pecos. Crop production problems are largely concerned with efficiency in storing and using the soil moisture available and with control of erosion. Grazing lands in the western two-thirds of the state also have the problems of soil moisture storage and utilization. Productivity of grazing lands in eastern Texas is limited by fertility, in most instances, and by inadequate moisture especially during the summer months.

Coast Prairie soils and soils along the major river bottoms have drainage problems that may be continuous or occasional, depending on location. Solutions to surface drainage problems are well known. However, internal drainage of the soil is a difficult problem that is as yet unsolved for the clay soils that are so common to the Coast Prairie.

Plant Nutrient Supply

The proper use of fertilizers to obtain optimal economic returns is complex. In Texas, use of nitrogen and phosphorus, as well as lime where needed, generally gives a good return on investment. Main areas giving economic response to fertilizers are the East Texas Timberlands, Cross

Timbers, Blackland Prairies, Grand Prairie, Coast Prairie, and most irrigated soils. How much fertilizer to apply to a given soil for a specified crop should be based on current soil tests. Cropping systems designed to provide adequate organic matter content and to supply sufficient nitrogen to crop plants should be coordinated with over-all fertility programs. The effect of soil fertility level on crop yields, under different moisture regimes and varying climatic factors, must be known if maximum production is to be obtained from the soil. It is particularly important to be able to predict the moisture and climatic conditions for a given area so that fertility practices can be followed to take maximum advantage of growing conditions. Plant nutrients, other than nitrogen, phosphorus, potassium, and calcium (lime), have received less attention and in Texas are used as fertilizer additions only occasionally.

Salinity

In some sections of Texas salinity problems are extensive and serious. The acreage of irrigated and supplementally irrigated land is increasing in the state, whereas high quality water supplies are decreasing. This means that the hazards caused by salinity will continue to increase as poorer quality water must be utilized. Perhaps the most serious aspect of salinity is that it affects crop yields on some of the most productive land in the state. Many thousands of acres have been "salted out."

Salinity problems are more prevalent in the semiarid and arid regions but are not confined to these areas. Most irrigated areas of the Trans-Pecos are plagued with salinity problems. Salt problems exist along the entire length of the Rio Grande River from New Mexico to the Gulf Coast. The lower Rio Grande Valley area is continually endangered because of the sensitivity of citrus and vegetables to salts. Along the Gulf Coast, some areas are experiencing encroachment of saline waters following pumping of ground waters for industrial and municipal needs. Rice farmers are also encountering salt problems in some areas. In North Texas, production of irrigated valleys along the Red River has been reduced by high salinity of ground waters. In extensively irrigated areas of the High Plains, gradual depletion of good quality ground waters means that sooner or later farmers may be forced to use waters of poorer quality from lower strata.

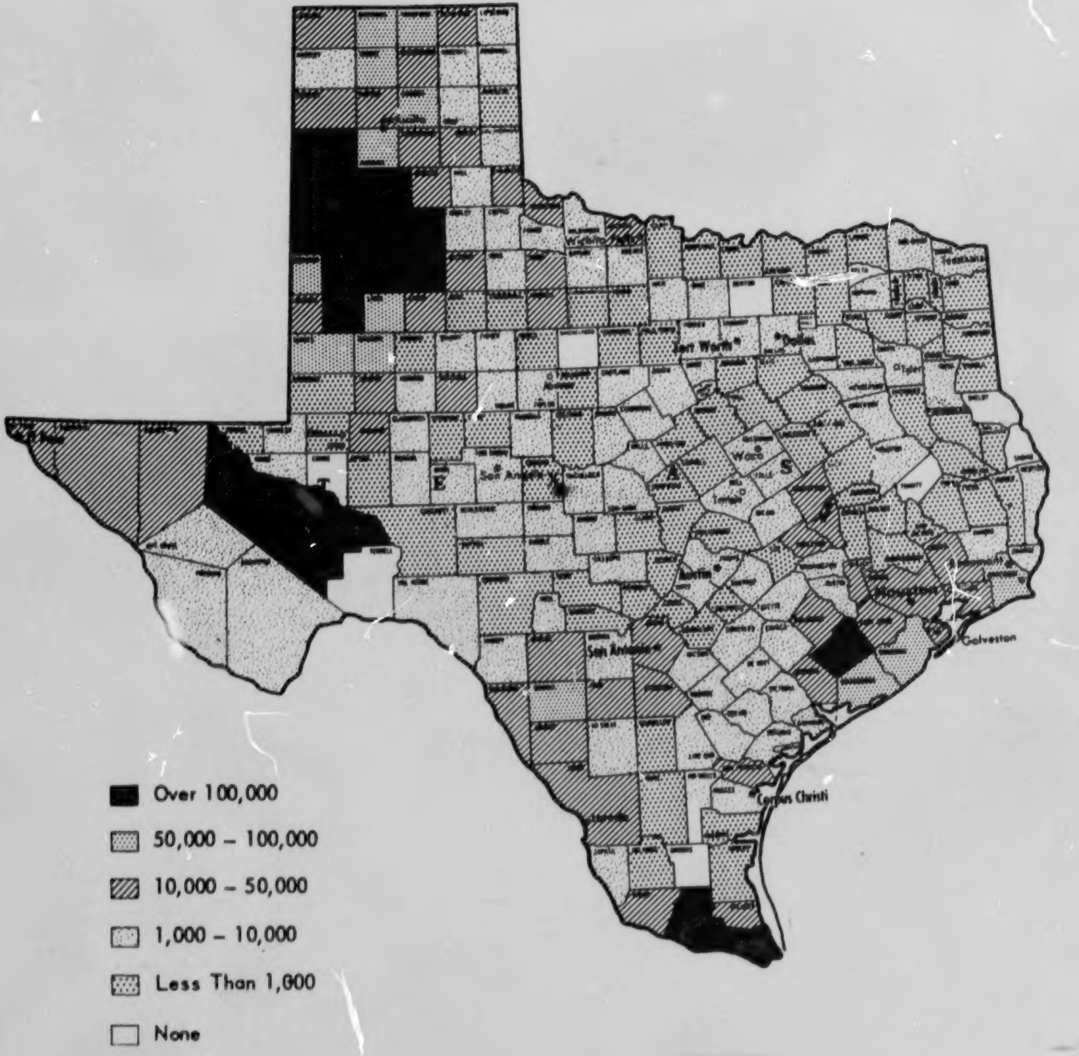
Soil Physical Condition

The effect of the physical condition of soil and its structure on soil productivity is important. With good soil structure, root systems are larger, more extensive, and better able to extract the moisture and nutrients necessary for optimum growth. Clay soils usually do not permit rapid entry of water and typically have slow internal drainage. This results in poor aeration and aggravates drainage problems. Many Texas soils have, or tend to develop, layers that reduce water movement through otherwise permeable soil and that may restrict root penetration if the condition is severe. Some of these layers are the result of natural soil formation processes, while others develop as the result of tillage operations.

Soil tilth and water intake are closely related to organic matter content of the soil. Major objective of crop rotation, managing crop residue and using soil-improving crops are to maintain a satisfactory organic matter level in the soil and to provide nitrogen for plant use.

Susceptibility of soils to wind and water erosion is directly related to physical condition, as is its efficiency in storing water for crops. Conservation cropping systems, conservation tillage farming practices, use of cover crops, and strip cropping affect this relationship and are desirable for both erosion control and moisture conservation.

The maintenance of soil in a condition that provides a favorable physical medium for plant root development is an important part of the management program. This is likely to become more important as farming operations become intensive.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Corpus Christi
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▨ 50,000 – 100,000
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▨ 1,000 – 10,000
▨ Less Than 1,000
☐ None

Figure 5. DISTRIBUTION OF IRRIGATED ACREAGE BY COUNTIES, 1974

TEXAS SOILS AND THE STATE ECONOMY

The population pattern of the state reflects the influence of both soil resources and the development of industry. Texas had a population in 1980 of about 13.2 million. The number of people in the state has steadily increased over the years, and it is predicted that a further rapid increase will occur in the next few years. Table 1 gives the population trends showing that as Texas has developed industrially, people have moved from the farm into the industrial centers of the state. This is borne out by the concentration of people in the Dallas, Fort Worth, and San Antonio areas of the central portion of the state and the high concentrations along the coast in near Beaumont, Houston, Corpus Christi, and Brownsville. In the western areas, El Paso, Lubbock, and Amarillo are population centers.

Table 1. TOTAL POPULATION AND FARM POPULATION TRENDS IN TEXAS

POPULATION			
YEAR	TOTAL	FARM	PERCENT OF TOTAL
1910	3,922,000	2,293,000	58.5
1920	4,723,000	2,314,000	49.0
1930	5,844,000	2,359,000	40.4
1940	6,423,000	2,160,000	28.0
1950	7,711,000	1,292,000	16.8
1960	9,580,000	694,000	7.2
1970	11,195,000	472,000	4.2
1973*	11,794,000	445,900	3.8

– Census of Population, U.S. Department of Commerce
*Estimated

LAND VALUE

A natural resource is a product of nature that is used by people to aid them in the achievement of goals. Land is vital to people's goals. Therefore, with the increase of population in Texas, land values have steadily gone up. Table 2 indicates this trend clearly for recent years, showing the median price per acre for rural land and the percentage change.

One of the major factors influencing the price of land is the conversion of rural land to nonagricultural use. Prior to World War II, monetary returns to the land resulting from agricultural enterprises had a great influence on rural land prices. As competition for rural land for nonagricultural use increased, the returns from agricultural enterprises became secondary in establishing the selling price of land.

Table 2 indicates that the median price per acre for rural land in 1974 was about $425 per acre. However, the price varies greatly depending on location within the state. Figure 6 depicts the median price per acre of rural land as estimated by State Planning Regions 1974.

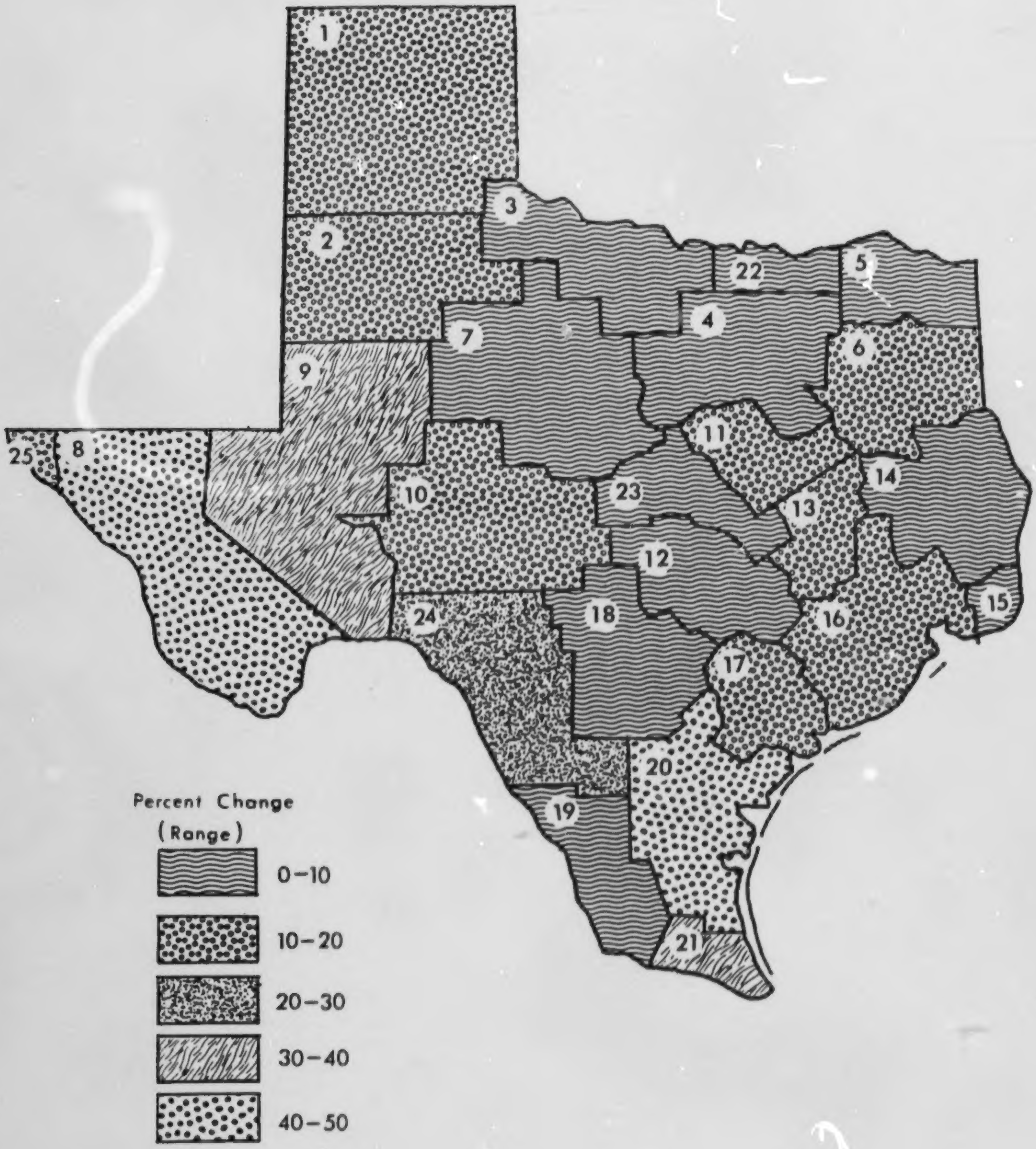
Table 3 indicates that the number of farms in Texas has decreased over recent years; however, individual farms are larger than in years past. Also, there has been an increase in the cash receipts from agricultural commodities (Table 4).

Table 2. MEDIAN PRICE PER ACRE OF RURAL LAND AND PERCENTAGE CHANGE: TEXAS 1963-1979

YEAR	MEDIAN PRICE PER ACRE	PERCENT CHANGE
1963	$135	
1964	151	11.9
1965	163	7.9
1966	170	4.3
1967	185	8.8
1968	200	8.1
1969	225	12.5
1970	240	6.7
1971	263	9.6
1972	293	11.4
1973	350	19.5
1974	425	21.4
1975	454	6.8
1976	475	4.6
1977	506	6.5
1978	574	13.4
1979	624	8.7

Table 3. SELECTED STATISTICS FOR TEXAS FARMS, 1954, 1959, 1964, 1969, 1974

ITEM	YEAR				
	1954	1959	1964	1969	1974
Cash receipts from all commodities (in millions)	$ 1,941.2	$ 2,281.5	$ 2,281.5	$ 2,669.0	$ 5,638
Total number of farms	292,947	227,071	205,110	213,550	174,068
Average number of acres per farm	497.7	630.7	690.9	667.6	771
Average investment in land and buildings	$ 30,711	$ 51,787	$ 77,756	$ 99,133	$188,000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Percent Change
(Range)
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10–20
20–30
30–40
40–50

Figure 6. MEDIAN PRICE PER ACRE

Table 4. CASH RECEIPTS* FROM FARM MARKETING, TEXAS

	1950	1960	1970	1975	1978
Crops	1,215,538	1,258,286	1,264,766	2,759,514	2,901,779
Livestock and livestock products	882,253	983,189	1,956,991	3,076,782	4,646,194
Total crops and livestock	2,097,791	2,241,475	3,221,757	5,836,296	7,547,973

*in thousand dollars

Land prices in Texas have been strongly influenced by capital from outside of agriculture such as purchases of hobby farms by professional people or investment purchases by individuals and corporations. Lands used in the development of cities, industrial sites, and resort areas are usually priced too high for agricultural utilization. This situation is becoming more generally statewide with the passing years. However, agricultural production is still a vital force in the economy of the state, affecting a large segment of the population.

Farm Products and Income

The farm population in Texas has continually declined to a low in 1970 of 4.2 percent of the state's total population. This is slightly lower than for the nation as a whole. Adoption of new technology and a more efficient farm business organization has permitted fewer people to produce greater volumes of agricultural products. Table 5 indicates yields per acre of selected crops.

Table 5. TEXAS ANNUAL CROP PRODUCTION SUMMARY

	1974	1976	1978
		YIELD PER ACRE	
Corn, grain	92.0 bu	120 bu	98 bu
Cotton lint, American-Pima	359 bale	480 bale	480 bale
Oats	27.0 bu	37.0 bu	32.0 bu
Peanuts	1,435 lbs	1,500 lbs	1,450 lbs
Rye	8.0 bu	14.0 bu	14.0 bu
Sorghum, grain	52.0 bu	50.5 bu	2,744 lb/cwt
Soybeans	30.0 bu	26.0 bu	26.0 bu
Wheat	16.0 bu	22.0 bu	20.0 bu

SPECIFIC SOIL RESOURCES*

Texas has an approximate land area of 169 million acres or about 263,000 square miles. A wide range of climate, vegetation, and soils occur. The state is divided into 15 land resource areas based on similarity of soils, geology, topography, climate, vegetation, and land use.

A discussion of each area, shown in Figure 7 follows.

1. TRANS-PECOS—Approximately 18.5 million acres. Mountain ranges and rough stony areas, with intermixed flat basins and plains, with slow to rapid surface drainage. Some basins do not have surface drainage.
   Elevation: 2,500 - 8,751 feet, the highest point in Texas (Guadalupe Peak in Culberson County).
   Annual rainfall: 8 - 18 inches; mostly less than 12 inches.
   Annual frost-free period: 220 - 245 days.

   Soils:
   - Uplands—Light reddish brown to brown silt loams, loams, silty clay loams, clay loams, clays, and sands (mostly calcareous, some saline) over reddish, loamy to clayey (calcareous, gypsic, or saline) subsoils. Many areas of shallow soils and rock lands. Sizeable areas of deep sands. Main series: Hoban, Reeves, and Reagan (lower basins); Brewster, Verhalen, and Musquiz (mountains and valleys); Lozier and Rockland (stony plateaus); Hueco and Wink (sands soils); and Hollomon (shallow over gypsum).
   - Bottomlands—Dark grayish brown to reddish brown, loamy and clayey calcareous, alluvial soils. Some are saline. Main series: Harkey, Gila, Vinton, Tigua, Glendale, Saneli, Pecos, Arno, and Toyah.

   Vegetation:
   - Uplands—At higher elevations, short grasses, some oak, and piñon and ponderosa pine; at lower elevations, short grasses, and desert shrubs, including salt-tolerant plants.
   - Bottomlands—Bunch grasses, mesquite, and desert shrub.

   Soil Management Considerations:
   Irrigation water, salinity control, nitrogen and phosphorus fertilizers, and range utilization.

   Land Use and Potentials:
   In the uplands, over 95 percent of the area is rangeland; however, irrigated crops contribute much to the economy. Cotton, alfalfa, grain sorghum, cantaloupes, and sugar beets are grown.

   In the bottomlands, cotton, alfalfa, grain sorghum, and vegetables are main crops.

   Mountains, parks, and access routes to Mexico attract many tourists. Further development of rangelands, recreation facilities, and irrigation agriculture are main potentials.

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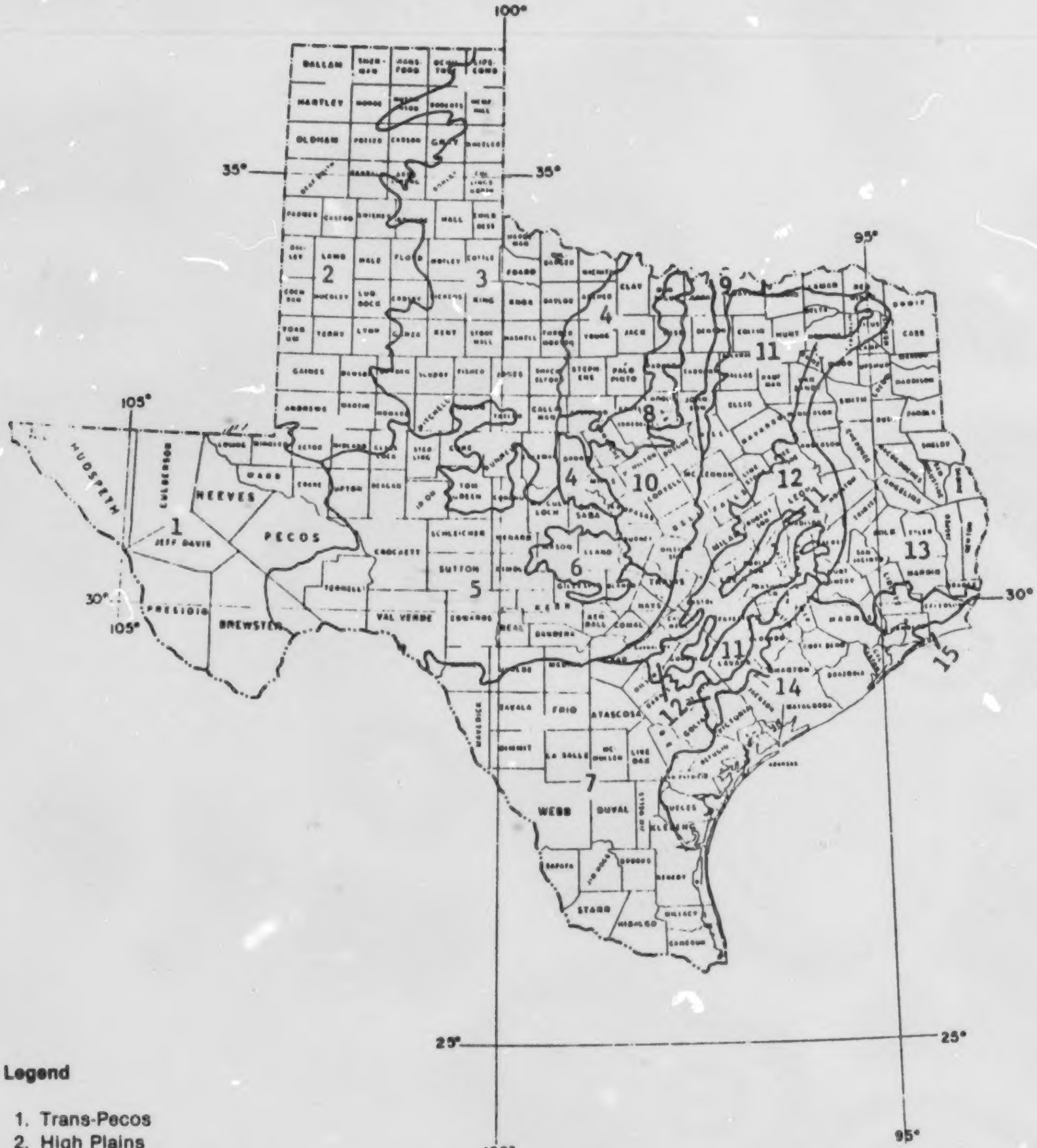
*Adapted from the Texas Agricultural Experimental Station Bulletin B-1070.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CULBERSON
REEVES
PECOS
JEFF DAVIS
PRESIDIO
BREWSTER
VAL VERDE
CROCKETT
SUTTON
SCHLEICHER
EDWARDS
FRIO
ATASCOSA
WEBB
DUVAL
STARR
HIDALGO

Legend

1. Trans-Pecos
2. High Plains
3. Rolling Plains
4. North Central Prairies
5. Edwards Plateau
6. Central Basin
7. Rio Grande Plain
8. West Cross Timbers
9. East Cross Timbers
10. Grand Prairie
11. Blackland Prairie
12. Claypan Area
13. East Texas Timberlands
14. Coast Prairie
15. Coast Marsh

Figure 7. MAJOR LAND RESOURCE AREAS OF TEXAS

2. HIGH PLAINS—Approximately 20 million acres. Nearly level, smooth, high tableland with slow to moderate surface drainage and many small, shallow lakes or *playas.*
Elevation: 3,000 - 4,000 feet.
Annual rainfall: 14 - 21 inches
Annual frost-free period: 180 - 220 days

Soils:
- Uplands—Dark brown to reddish brown; mostly deep neutral to calcareous; clay loams, sandy loams, and sands with subsoils of calcareous earths, varying from loamy to clayey and from pink to brown. Caliche is present under most soils at various depths. Main series: Pullman, Olton, Amarillo, Acuff, Arvana, Mansker, Estacado, Portales, Brownfield, Patricia, and Tivoli. Also, some loamy soils, shallow over caliche. Main series: Potter and Kimbrough.
- Bottomlands—Very minor; small acreages of brown, loamy, calcareous alluvial soils. Main series: Spur and Bippus.

Vegetation:
Predominantly short grasses with limited areas of mesquite, sand, sage, yucca, and juniper.

Soil Management Considerations:
Water conservation for dryland and irrigation farming, wind erosion, and nitrogen and phosphorus fertilizers.

Land Use and Potentials:
About 60 percent of the area is cropland, one-half of which is irrigated; however, range is also important. Cotton, grain sorghum, corn, wheat, soybeans, vegetables, and sugar beets are major crops. Urban industries are expanding. Intensification of irrigated and nonirrigated agriculture, expanded ranching, and livestock industries, and additional urban development are main potentials.

3. ROLLING PLAINS—Approximately 23 million acres. Broad, nearly level to rolling, grass and brush covered plains with moderate to rapid surface drainage and entrenched well-drained stream valleys.
Elevation: 1,000 - 3,000 feet.
Annual rainfall: 18 - 28 inches.
Annual frost-free period: 185 - 235 days.

Soils:
- Uplands—Pale brown through reddish brown to dark grayish brown; neutral to moderately alkaline; loamy sands, loams, sandy loams, clay loams, and clays over reddish, loamy to clayey subsoils. Some are calcareous. Some soils are saline, some are shallow and stony, and some are deep sands. Main series: Miles, Woodward, Carey, Tillman, Sagerton, Bukreek, Rotan, Springer, Vernon, Nobscot, and Heatly (northern two-thirds); Abilene, Rowena, Mereta, and Tarrant (southern one-third).
- Bottomlands—Minor areas of reddish brown, sandy to clayey, calcareous, alluvial soils. Main series: Mangum, Clairemont, Yomont, Miller, Port, Yahola, Lincoln, Gageby, and Colorado.

Vegetation:
Short and bunch grasses with mesquite and local areas of scrub oak and shin oak.

Soil Management Considerations:

Wind erosion, salinity control, soil moisture, conservation, range utilization, and nitrogen and phosphorus fertilizers.

Land Use and Potentials:

Over three-fourths of the land is in range; however, drylands and irrigated grain sorghum, wheat, cotton, and forages are important crops. Intensification of present land use is the main potential.

4. NORTH CENTRAL PRAIRIES—Approximately six million acres. Undulating prairies and nearly level valleys with slow to rapid surface drainage, interspersed with rapidly drained sandstone and shaly ridges and hills with scrub oak and mesquite vegetation.
Elevation: 900 - 1,400 feet.
Annual rainfall: 25 - 30 inches.
Annual frost-free period: 225 - 240 days.

Soils:

- Uplands—Shallow to deep, brown, sandy loam to silt loam, slightly acid soils over red to gray, neutral to alkaline, clayey subsoils. Some contain limestone fragments; some have dense claypans. Main series: Kirkland, Renfrow, Bluegrove, Stoneburg, Oben, Owens, Throck, Truce, Waurika, Bonti, Hensley, Yates, and Tarrant.
- Bottomlands—Minor areas of reddish brown to dark gray, loamy and clayey, neutral to calcareous alluvial soils. Main series: Miller, Clairemont, Yahola, Mangum, Frio, Elandco, Deleon, and Gowen.

Vegetation:

- Uplands—Scrub oak, mesquite, and tall and short grasses.
- Bottomlands—Hardwood and mesquite.

Soil Management Considerations:

Moisture utilization, brush control, and nitrogen and phosphorus fertilizers.

Land Use and Potentials:

Over three-fourths of the land is in range. Grain sorghum, wheat, oats, peanuts, and fruits are grown on the better soils. Intensification of farming and range improvement are best potentials.

5. EDWARDS PLATEAU—Approximately 23 million acres. A rapidly drained, brush- and grass-covered stony plain with broad, flat to undulating divides; hilly, broken, and very stony adjacent to the draining ways, less sloping stream valleys.
Elevation: 1,200 - 3,000 feet.
Annual rainfall: 12 - 32 inches.
Annual frost-free period: 220 - 260 days.

Soils:

- Uplands—Dark, calcareous clays and clay loams, mostly shallow and stony. Some deeper, less stony soils on the flat divides. Main series: Kavett, Valera, Mereta, Tarrant, Brackett, and Tobosa (eastern two-thirds); Ector, Upton, and Reagan (western one-third).
- Bottomlands—Minor areas of dark, calcareous, clayey alluvial soils. Main series: Frio and Rioconcho.

Vegetation:

- Uplands—Live oak, shin oak, cedar, mesquite, and short grasses, changing to desert shrub in the westernmost counties.
- Bottomlands—Hardwood species, including oak and pecan.

Soil Management Considerations:

Brush control; range management for cattle, goats, sheep, and deer; and nitrogen and phosphorus fertilizers.

Land Use and Potentials:

About 98 percent of the land is in range. This is a major region of wool and mohair production. A large deer population also utilizes the ranges. Production of small grain, grain sorghum, forage, and hay crops is limited. Range for cattle, goats, sheep, and deer, with hunting and other recreation, are major potentials.

6. CENTRAL BASIN—Approximately 1.5 million acres. Rolling to hilly and stony, scrub oak, and brush covered area, with moderate to rapid surface drainage.
Elevation: 1,000 - 1,800 feet.
Annual rainfall: 25 - 30 inches.
Annual frost-free period: 220 - 230 days.

Soils:

- Uplands—Reddish brown to brown; neutral to slightly acid; mostly gravelly and stony sandy loams shallow over granite, limestone, gneiss, and schist; deeper, less stony, sandy loam soils in the valleys. Main series: Castell, Ligon, Pontotoc, Perdernales, Ketemcy, Hensley, and Oben.
- Bottomlands—Minor areas of dark gray, neutral to calcareous alluvial soils. Main series: Frio and Gowen.

Vegetation:

- Uplands—Mesquite, live oak, post oak, and tall and short grasses.
- Bottomlands—Hardwood species, including oak and pecan.

Soil Management Considerations:

Brush control, moisture management, and nitrogen and phosphorus fertilizers.

Land Use and Potentials:

About 90 percent of the area is rangeland. Deer hunting leases are common. Some small valleys are cultivated to peanuts, fruits, and grain crops. Range, wildlife, and recreation with some intensive farming are major potentials.

7. RIO GRANDE PLAIN—Approximately 20.5 million acres. A nearly level to rolling brushy plain with slow to rapid surface drainage.
Elevation: Sea level to 1,000 feet.
Annual frost-free period: 260 - 340 or more days.

Soils:

- Uplands—Dark, calcareous to neutral, clayey soils over firm clayey subsoils. Main series: Catarina and Montell. Grayish to reddish brown, neutral to slightly acid, loamy to sandy soils over red to gray, yellow and red mottled subsoils at varying depths. Main series: Duval, Webb, San Antonio, Migel, and Nueces. Brown, loamy, calcareous to neutral soils over brown to reddish subsoils. Main series: Uvalde, Knippa, Willacy, Hidalgo, and Brennan.

- Bottomlands—Brown to gray, calcareous silt loams to clayey, alluvial soils. Main series: Matamoros, Camargo, Grulla, and Rio Grande. On adjacent low terraces—Harlingen, Laredo, Raymondville, and Lagloria.

Vegetation:
- Uplands—Thorny shrubs, mesquite, and tall and short grasses.
- Bottomlands—Thorny shrubs, mesquite, hardwoods, and bunch grasses.

Soil Management Considerations:
Drainage, salinity control, water management for irrigation, nitrogen and phosphorus fertilizers, and brush control.

Land Use and Potentials:
Range is the major land use; however, irrigated and dryland cropping of citrus, vegetables, cotton, and forages are also important in the economy, along with white wing dove hunting and winter tourism. Expanded irrigation and dryland agriculture, livestock production, recreation, and winter resorts have good potentials.

8. WEST CROSS TIMBERS—Approximately two million acres. Undulating to gently rolling scrub oak woodland area, with rapid surface drainage.
Elevation: 900 - 1,500 feet.
Annual rainfall: 28 - 32 inches.
Annual frost-free period: 230 - 240 days.

Soils:
- Upland—Light, slightly acid, loamy sands and sandy loams over yellowish brown to red clayey subsoils. Main series: Windthorst, Nimrod, Duffau, Eufaula, Weatherford, Chaney, Demona, Patilo, and Arenosa.
- Bottomlands—Small areas of dark, neutral to calcareous, clayey and loamy alluvial soils along minor streams. Main series: Frio, Gowen, Bunyan, Pulexas, and Elandco.

Vegetation:
- Uplands—Scrub oak and tall bunch grasses.
- Bottomlands—Hardwoods, mainly oak, pecan, and elm species.

Soil Management Considerations:
Use of nitrogen, phosphorus and potassium fertilizers, erosion control, and rainfall utilization.

Land Use and Potentials:
Range and pasture utilize over half the land. Peanuts, fruits, vegetable, and forage are major crops. Intensification of farming and pasture and range improvement are main potentials.

9. EAST CROSS TIMBERS—Approximately one million acres. A gently rolling narrow strip of scrub oak woodlands, with moderate to rapid surface drainage.
Elevation: 500 - 700 feet.
Annual rainfall: Approximately 35 inches.
Annual frost-free period: 230 - 250 days.

Soils:
- Uplands—Light, slightly acid, loamy sands and sandy loams over yellowish brown to red clayey subsoils. Main series: Gasil, Konsil, Rayex, Birome, Aubrey, Callisburg, Crosstell, Heaton, and Arenosa.

- Bottomlands—Minor areas of brown, slightly acid, loamy alluvial soils, mainly the Gowen series, along minor streams; also some minor areas of dark, clayey, neutral to calcareous alluvial soils. Main series: Pulexas, Bunyan, and Trinity.

Vegetation:
- Uplands—Oak trees and tall bunch grasses.
- Bottomlands—Hardwoods, mainly oak and pecans.

Soil Management Considerations:
Use of nitrogen, phosphorus, and potassium fertilizers; erosion control; and utilization of moisture.

Land Use and Potentials:
Range, pasture, and urban development are major land uses; some peanuts, fruits, vegetables, and forage crops are produced. Urban development, intensification of present cropping, and dairying for urban markets are major potentials.

10. GRAND PRAIRIE—Approximately seven million acres. Undulating to hilly prairies, with moderate to rapid surface drainage.
Elevation: 600 - 1,100 feet.
Annual rainfall: 30 - 35 inches.
Annual frost-free period: 230 - 240 days.

Soils:
- Uplands—Dark, deep to shallow, and stony, calcareous clays with subsoils of lighter, limy earths and limestone fragments. Main series: Sanger, Slidel, San Saba, Denton, Crawford, Krum, Purves, Tarrant, Brackett, and Blanket.
- Bottomlands—Minor areas of reddish brown, loamy to clayey, calcareous alluvial soils. Main series: Ships, Norwood, and Yahola. Some dark clayey calcareous to neutral, alluvial soils. Main series: Frio, Bosque, Trinity, Tinn, and Gowen.

Vegetation:
- Uplands—Tall bunch grasses, short grasses, live oak, and cedar.
- Bottomlands—Hardwoods, mainly species of oak, elm, and native pecan.

Soil Management Considerations:
Use of nitrogen and phosphorus fertilizers, water management, and brush control.

Land Use and Potentials:
About three-fourths of the area is in range. Some small grain, grain sorghum, corn, wheat, and forage crops are grown. Range is the major land use potential, but grain and forage crop production could be intensified locally.

11. BLACKLAND PRAIRIE—Approximately 13 million acres. Nearly level to rolling prairies, with moderate to rapid surface drainage. The flood plains are slowly drained; some areas are wooded.
Elevation: 250 - 700 feet.
Annual rainfall: 30 - 45 inches.
Annual frost-free period: 230 - 280 days

Soil:
- Uplands
    - Blacklands—Dark, calcareous, clayey soils changing gradually with depth to light marls or chalks. Main series: Ferris, Houston Black, Austin, Stephen, Heiden, Branyon, and Dalco.
    - Graylands—Neutral to slightly acid clays to sandy loams over firm, dark gray to red, mottled, clayey subsoils, all becoming calcareous in the substratum. Main series: Burleson, Wilson, Crockett, and Mabank.
- Bottomlands—Reddish brown to dark gray, slightly acid to calcareous, loamy to clayey, alluvial soils. Main series: Ships, Weswood, Norwood, Pledger, Jaufman, Oran, Trinity, and Tinn.

Vegetation:
- Uplands—Tall bunch grasses; some mesquite and oaks in the Graylands.
- Bottomlands—Mainly species of oak, elm, cottonwood, and native pecan trees.

Soil Management Considerations:

Moisture utilization, erosion control, cotton root rot disease, and nitrogen phosphorus fertilizers.

Land Use and Potentials:

Nearly half the area is cropland, with cotton, grain sorghum, corn, wheat, and forages as major crops. Tame pastures and meadows occupy about one-fourth the land area. Pecan groves and dryland and irrigated crops are important in the floodplains. Major potentials include intensification of production of cotton, food and feed grains, forages, and pecans, with additional output of beef and dairy products for an expanding urban complex.

12. CLAYPAN AREA—Approximately eight million acres. Nearly level to gently rolling woodland, savannah to brush area (Post Oak Belt) with moderate surface drainage.
Elevation: 200 - 500 feet.
Annual rainfall: 30 - 45 inches.
Annual frost-free period: 235 - 280 days.

Soils:
- Uplands—Gray, slightly acid, sandy loams, commonly thin over gray, mottled or red, firm, clayey subsoils. Some deep, sandy soils with less clayey subsoils exist. Main series: Lufkin, Axtell, and Tabor (thin surface claypan soils); Freestone, and Patilo (thick surface sandy soils).
- Bottomlands—Reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial soils. Main series: Ships, Norwood, Pledger, Kaufman, Trinity, Tuscumbia, and Tinn.

Vegetation:
- Uplands—Scattered stands of post oak and blackjack oak with tall bunch grasses; yaupon and other underbrush prevalent in places.
- Bottomlands—Hardwoods, predominantly oak with pecans in some areas.

Soil Management Considerations:
- Uplands—Drouthy soils with claypans; nitrogen, phosphorus, and potassium fertilizers; and cool season cropping to utilize moisture.
- Bottomlands—Nitrogen and phosphorus fertilizers, local drainage, and land shaping for irrigation.

Land Use and Potentials:

In the uplands, much land is in woodland and brush range. Many areas are under lease for deer hunting. Tame pasture and cool season forage crops are important.

In the bottomlands, grain sorghum, cotton, corn, forage crops, tame pasture, and pecans are important. Irrigation is common. Winter pastures, deer hunting, and dairy and beef production are major upland potentials. Intensification of presently irrigated agriculture and increased production of vegetables and pecans are bottomland potentials.

13. EAST TEXAS TIMBERLANDS—Approximately 16 million acres. Nearly level to gently undulating forested area with slow to rapid surface drainage.
Elevation: 200 - 700 feet.
Annual rainfall: 40 - 56 inches.
Annual frost-free period: 235 - 265 days.

Soils:

- Uplands—Light to red, acid, sandy loams and sands over gray, yellow, red, or mottled sandy loam to clay subsoils. Subsoils of finer textures are a few inches to three or more feet below the surface. Main series: Bowie, Kirvin, and Troup. Main series in the hilly Redlands are: Nacogdoches, Ruston, and Woodtell. In the poorly drained Flatwoods and Big Thicket: Segno, Splendora, Sorter, Hockley, Caddo, Guyton, Waller, and Wrightsville.

Vegetation:

- Uplands—Loblolly, shortleaf and longleaf pine with associated hardwood species, mainly oak.
- Bottomlands—Hardwoods, mainly species of oak and sweetgum with some pine and cypress.

Soil Management Considerations:

Local drainage; erosion control; and ample nitrogen, phosphorus, potassium fertilizers with applications of lime and secondary and trace elements.

Land Use and Potentials:

About two-thirds of the area is forested, with commercial pine and hardwood timber produced in the uplands. Commercial hardwoods are more important in the bottomlands. Tame pasture, feed grains, forages, fruits, and vegetables are main crops. Water resource development and recreation are also important to the economy. Forests and lakes make the area especially well-suited for recreation and industrial expansion. A potential exists for additional fruit, vegetable, and beef and dairy production.

14. COAST PRAIRIE—Approximately nine million acres. Nearly level plain with slow surface drainage.
Elevation: Sea level - 250 feet.
Annual rainfall: 28 - 56 inches.
Annual frost-free period: 250 - 320 days.

Soils:

- Uplands—Dark, neutral to slightly acid clay loams and clays, changing gradually with depth to light calcareous clays. Main series: Lake Charles, Beaumont, Edna, and Bernard. Further south, in the subhumid Coast Prairie (Coastal Bend), soils are less acid and some are calcareous. Main series: Victoria, Orelia, and Clareville.

Light acid sands and darker, loamy to clayey soils (some saline and sodic) lie in a narrow band along the coast. Main series: Harris and Galveston.

In a narrow belt inland from the dark clayey soils, lighter acid, fine sandy loam soils with gray to brown and red mottled clayey subsoils are prevalent. Main series: Katy, Hockley, Wockley, Kenney, and Edna.

- Bottomlands—Reddish brown to dark gray, slightly acid to calcareous, loamy to clayey alluvial soils. Main series: Norwood, Ships, Oklored, Pledger, Kaman, Mantachie, and Urbo.

Vegetation:

- Uplands—Tall bunch grasses; on the coastal fringe, salt grasses.
- Bottomlands—Hardwoods, mainly oak species.

Soil Management Considerations:

Local drainage and land smoothing, ample nitrogen and phosphorus fertilizers, and special programs for pasture and range utilization.

Land Use and Potentials:

Cropland, range, and urban and industrial centers are major land use categories. Rice, grain sorghum, cotton, corn, and tame pasture are important crops. About one-third of the area is cultivated. Intensive dryland and irrigated cropping and livestock production are major potentials. Urban, industrial, and recreational developments are increasing rapidly.

15. COAST MARSH—Approximately 500,000 acres. Low, wet, marshy coastal area, often covered with sea water in places.
Elevation: Sea level to a few feet above sea level.
Annual rainfall: 40 - 55 inches.
Annual frost-free period: 270 - 300 days.

Soils:

Dark, poorly drained, sandy loams and clays and light, neutral sands, usually showing little textural change with depth. Some wetter soils are very high in organic matter (peaty); loamy and clayey soils are often saline. Main series: Harris and Galveston.

Vegetation:

Sedges, rushes, and salt grasses.

Soil Management Considerations:

Drainage for some crops; salinity control; and nitrogen, phosphorus, and potassium fertilizers.

Land Use and Potentials:

Higher areas are used for range and for urban, industrial, and recreational developments. Some areas are used for rice and vegetables. Most land is not well suited for cultivation. Lower marsh areas are used mainly for natural wildlife habitat. Main potentials are industrial development, wildlife preserves, recreation, and limited local crop production.

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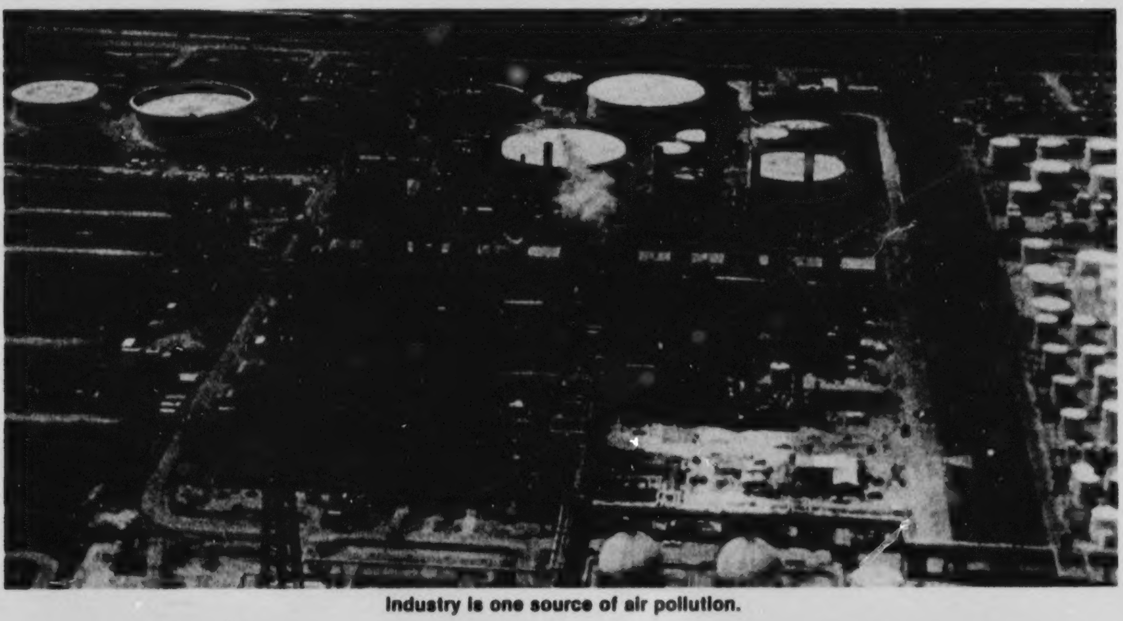
Air Resources of Texas

Air is a mixture of a number of gases consisting of about 78 percent nitrogen, approximately 21 percent oxygen, a small amount of carbon dioxide, and traces of other gases, most of which are inert. People can survive for days without food or water but only a few minutes without air. The average person breathes about 35 pounds of air each day, approximately six times the daily intake of food and drink.

The air supply in Texas is limited and should be considered one of the state's most important natural resources. Because people continually reuse air, it is imperative that air of good quality be maintained. Air cannot be replenished as can soil and trees or purified as can water. Air is breathed as it exists—too often filled with pollutants.

In the United States, the air is filled with more than 200 million tons of air pollution each year. This pollution cannot be blamed on any one aspect of society because the trends of economic expansion, urban growth, technological progress, and increasing use of motor vehicles all contribute to the problem. The true dimensions of the threat that air pollution poses are only beginning to be understood. Pollution discolors, corrodes, and damages a wide variety of structures in cities and towns. It threatens forests and farm crops as well as birds, wildlife, and domestic animals. Air pollution also is a costly problem. Overall, the cost of pollution damage to property has been estimated to be $70 per person per year.



Industry is one source of air pollution.

Air pollution constitutes a serious health problem to all, especially young children, senior citizens, and those suffering from chronic respiratory diseases including bronchitis and emphysema. Lung cancer also is found twice as often in air polluted cities as in rural areas. Air pollution also contributes to or aggravates symptoms of the common cold, pneumonia, and bronchial asthma.

The problems of air pollution are not going to disappear overnight. By the year 2000, 85 percent of the more than 320 million persons in the United States will live in cities. They will drive more cars, use more power and electricity, and create more garbage and waste than they do now.

Air pollution can cause minor irritating discomfort or constitute a major health hazard.

PRINCIPAL POLLUTANTS AND THEIR EFFECTS

Carbon Monoxide (CO) is a colorless, odorless, poisonous gas produced when any material or substance with carbon such as coal, oil, gasoline, and natural gas is involved in incomplete combustion. At levels frequently found in heavy automobile traffic, it can produce headaches, loss of visual acuity, and decreased muscular coordination after several hours of exposure. At high levels, it causes loss of oxygen in the blood and kills brain activity.

Sulfur Oxides (SO_x) are compounds formed when coal and fuel oil, fuels containing sulfur, are burned and sulfur joins with oxygen in the air to form gaseous oxides of sulfur. Sulfur oxides are considered major air pollutants and are emitted into the air by fuel combustion, metal processing, trash burning, and chemical plants. In combination with moisture and oxygen, they form sulfuric acid. Sulfur oxides can harm people and vegetation; corrode metal and stone; affect paper, fabrics, and leather; and irritate the upper respiratory tract and lung tissue.

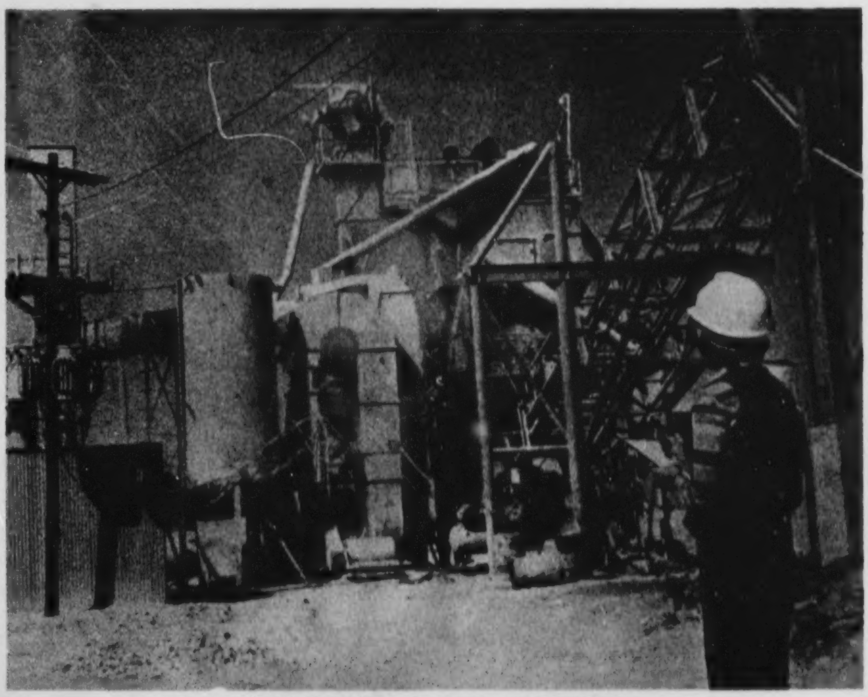
Nitrogen Oxides are considered major air pollutants, especially nitric oxide (NO) and nitrogen dioxide (NO_2). They are formed in the combustion of all types of fuels and are released into the atmosphere during combustion and certain chemical manufacturing operations. Nitrogen oxides contribute to photochemical smog and are partially responsible for the brownish haze that interferes with visibility. They can cause serious damage to plant life and property and can limit visibility. Exposure to high levels can cause lung irritation and increase respiratory diseases.

Hydrocarbons (HC) are any of the vast family of compounds containing carbon and hydrogen in various combinations, found especially in fossil fuels. Some hydrocarbons may be carcinogenic and can take part in the reaction with oxides of nitrogen to make photochemical smog. They are discharged chiefly by automobiles, petroleum refineries, and petrochemical plants.

Particulate Matter is composed of solid or liquid matter suspended in the air or in an emission, such as from automobile exhausts. Particulate matter varies in size, amount, density, and chemical composition and includes dust, smoke, fumes, spray, mist, and fog. Particulates can result from many kinds of industrial and agricultural operations and from combustion products, including automobile exhaust emissions. Particles soil clothes, dirty windowsills, scatter light, and can carry irritants and gases into the lungs.

Ozone (O_3) is an odorous, colorless, poisonous gas formed by the reaction of sunlight and hydrocarbons in the air. It is one of the major products in smog. In high concentrations, ozone can cause coughing, choking, headaches, and sever fatigue. It can damage the leaves of plants, crack rubber, deteriorate fabrics, and fade colors.

Many materials can become pollutants if they escape into the atmosphere. Some of the substances that can be toxic are asbestos, arsenic, lead, vinyl chloride, beryllium, and cadmium. The Texas Air Control Board is studying the potential for adverse health effects from exposure to low levels of toxic materials that can be emitted into the air. A Medical Resources Advisory Panel has been established to advise the Board and to evaluate the public health significance of exposure to each potentially toxic substance. Should the potential for impact on the public health from certain substances be discovered in any area, the Texas Air Control Board will act to reduce or eliminate the emissions to protect the public's health.

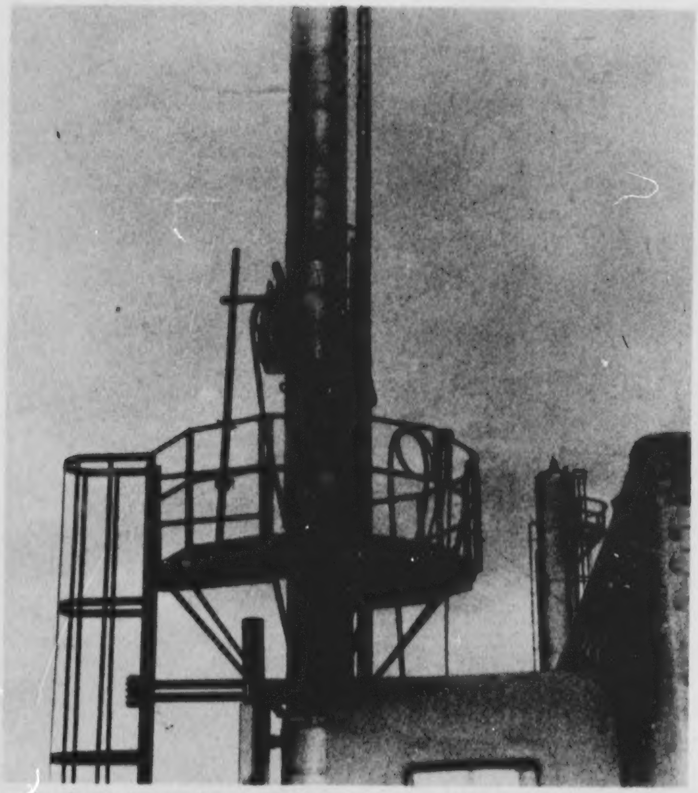


TACB investigator inspects hot mix plant.

METHODS OF DETECTING AND MEASURING AIR CONTAMINANTS

Air contaminants are emitted into the atmosphere in a solid, liquid, or gaseous form. The solids (particulate matter) are collected by the use of a high-volume air sampler, which draws air through a pre-weighed filter at approximately 40 cubic feet per minute. The filter then is removed and reweighed. The difference in weight is calculated and expressed in micrograms per cubic meter of air sampled. Respirable or inhaled particulate matter is collected by the use of the dichotomous sampler that separates particles into fractions larger than and smaller than approximately 3.5 microns in diameter. The filters are removed and reweighed and the difference is reported as micrograms per cubic meter. Gases are detected and measured by various precision instruments or devices designed specifically to identify and measure a particular gas substance.

Stack sampling is the preferred method of collecting and measuring the exact amount of pollutants being emitted through a single smoke stack. To sample the smoke, a hole is drilled in the stack and a probe is inserted. The stack gases and particles are drawn through the probe and trapped in various containers for laboratory analysis.



Smokestack sampling determines exact quantitites of contaminants emitted.

Data are collected from high volume sampler.

METHODS OF ELIMINATING OR REDUCING AIR CONTAMINANTS RELEASED INTO THE ATMOSPHERE

The technology for the control of air pollution is well known for most industrial processes. The most common methods of eliminating or reducing pollutants to a tolerable level are as follows:

- Destroying the pollutant by use of fire (limited to combustible matter)
- Masking or counteracting the pollutant by superimposing another odor to create a new odor sensation
- Collecting the pollutant by use of equipment to prevent its escape into the atmosphere. This may be done by:
    - Bag filters—Particulate-laden gases are passed through a woven fabric that removes the particles, allowing the gases to pass on.
    - Scrubbers—Pollutants that may cause water pollution problems are washed by use of a water shower.
    - Cyclones—Dust-laden gas is caused to swirl in a conical or cylindrical shell causing dust to collect on sides and drop into a hopper below.
    - Electrostatic precipitators—These use positive and negative electrodes. When an air stream carrying small dust particles or liquid droplets is passed between a wire, rod, or plate with a strong negative charge and a grounded surface, the suspended particulate matter is driven toward the grounded surface where it is deposited and removed from the air.
- Controlling pollution by dilution in the atmosphere. This is done by:
    - Use of tall stacks in which the polutant is discharged high enough so that the natural movement of the air currents will dilute and disperse the pollutant so as to render it harmless when it reaches the ground
    - Air zoning that involves community planning to prevent harmful ground concentrations within designated areas
    - Meteorological control of process operations in which manufacturing processes are curtailed or completely shut down during periods of adverse weather conditions

AUTOMOBILE EXHAUST EMISSIONS

Part of the American dream—automobile ownership—has caused a nightmare in most major metropolitan areas in the United States. The automobile that gives us convenient, luxurious transportation also helps diminish the quality of the air we breathe.

Pollutants emitted from automobiles include nitrogen oxides, hydrocarbons, and carbon monoxide. The chemical reaction of the nitrogen oxides, hydrocarbons, and sunlight forms photochemical oxidants (smog) that have been found to cause eye irritation and aggravate any existing respiratory condition.

The Federal Environmental Protection Agency has adopted standards to control the major pollutants emitted by automobiles. To comply with the standards, automobile makers equip cars with various emission control devices. The most commonly used device to reduce exhaust emissions is the catalytic converter.

Because the Federal Clean Air Act does not prohibit individual car owners from removing or dismantling converters, the Air Control Board established antitampering regulations for Texas. Tampering is punishable by a fine of $50 to $1,000 per act. In addition to being a violation of the law, tampering is an expensive waste because the car owner is dismantling equipment that cost from $200 to $300. Also, tampering can reduce fuel performance and mileage. For emission control systems to function effectively and to ensure maximum fuel economy, it is important that cars be tuned regularly and that emission control devices be maintained properly.

Obviously, the cooperation of every U.S. citizen is needed to help solve the complex automobile pollution problem.

Automobiles are a major source of air pollution.

LEGISLATION AND CONTROL AGENCIES

Because of the rapid growth of Texas cities, the expansion of industry, and the increasing use of automobiles as major factors in the deterioration of clean air resources, the Texas Legislature in 1965 passed the Clean Air Act of Texas, which created the Texas Air Control Board.

The Board is charged with setting up rules and air quality standards designed to safeguard the people of Texas. Regulations have been adopted to control air pollution from nitrogen compounds, smoke and suspended particulates, outdoor burning, sulfur compounds, motor vehicle emissions, toxic materials, and from volatile organic compounds. Regulations also cover permits for new construction or modification and air pollution emergency episodes.

The Texas Air Control Board comprises nine members. Included are an air pollution engineer, a licensed physician, a representative from industry, an agricultural engineer, and individuals from the general public. All members of the Board are appointed by the governor for overlapping terms of six years. The Board members are responsible for issuing rules and adopting regulations designed to safeguard the air resources from pollution.

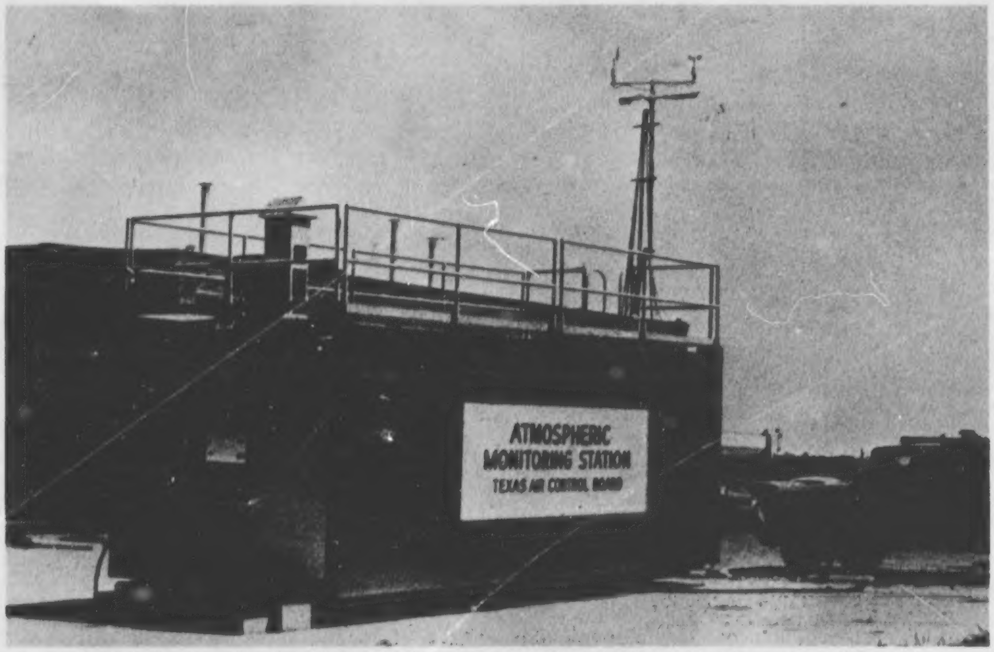
Initially, the Air Control Program was administered by the Texas Health Department, under the direction of the Air Control Board.

It was established by the Legislature as a separate agency in 1973. Since that time, the staff has grown to approximately 370 employees, with an operating budget of more than $9.8 million.

Its staff includes attorneys, professional engineers, environmental health specialists, and administrative personnel. The agency is divided into four major programs: Control and Prevention, Measurements and Analysis, Standards and Regulations, and Administrative Services. (See Organization Chart, page 34.)

The Texas Air Control Board has achieved success in its initial efforts to develop an effective, long-range air quality control program for Texas. The Board believes that both economic growth and reasonable control of air pollution can be achieved and has developed workable strategies to accomplish these twin goals. Most of the Board's activity has been devoted to reducing or eliminating existing problems. However, the Board's regulations provide engineering standards that can be used to install control equipment in new or expanded industrial plants, as well as in existing plants.

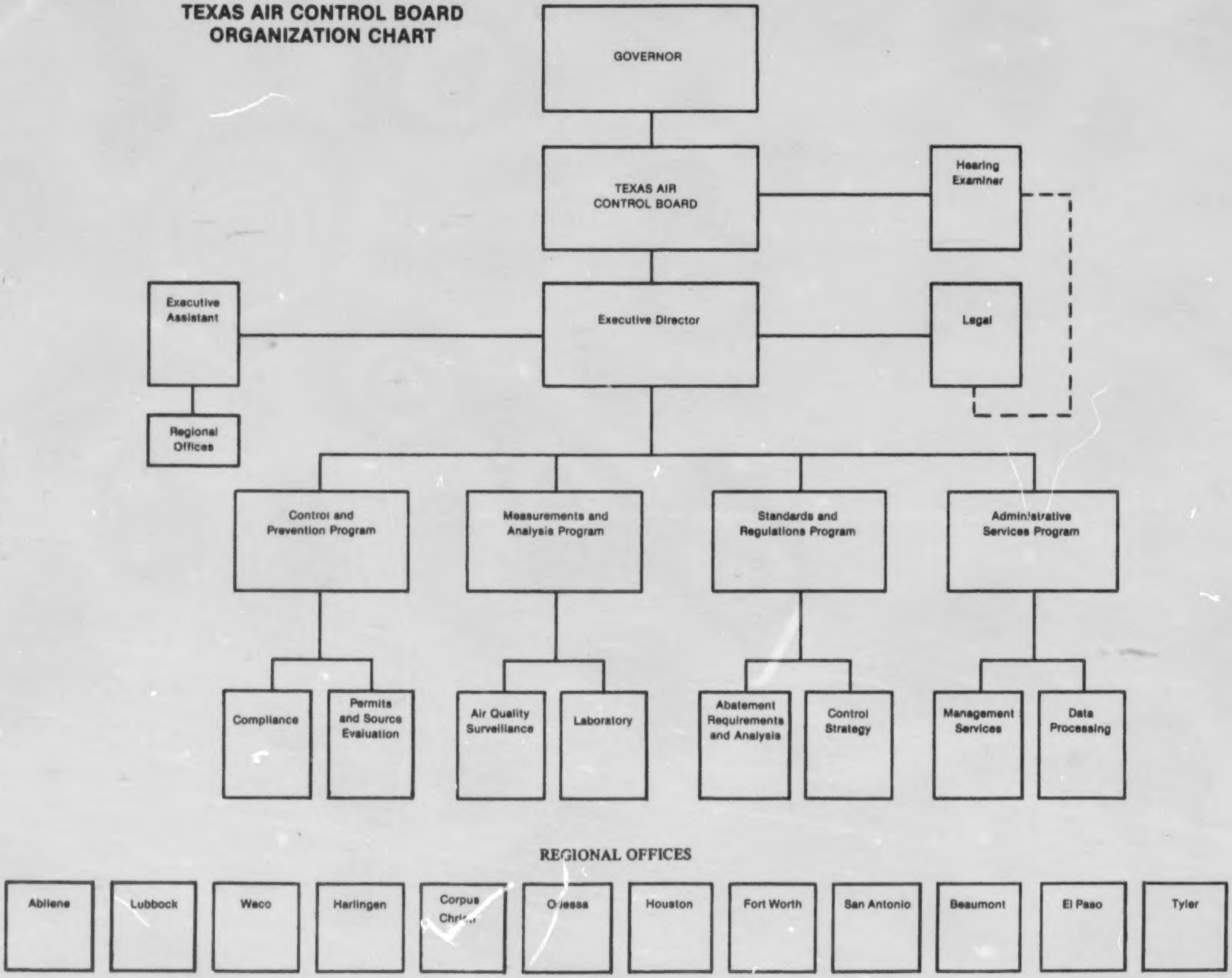
In carrying out its program, the Board has the authority to file suits and seek injunctions against offenders of its regulations. Penalties may be assessed up to $1,000 per day for each day of violation.



Twenty-four continuous air monitoring stations are located in major urban areas of Texas.

To determine the extent of air contaminants in the ambient atmosphere, the Board depends upon data gathered from its network of monitoring stations and samplers throughout Texas. The network is periodically reevaluated to meet monitoring needs. Twenty-four continuous air monitoring stations, called CAMS, are equipped both with air pollution and meteorological instruments that are read and reported through a digital recording system. The air pollution monitors record levels of ozone, carbon monoxide, sulfur dioxide, and nitrogen dioxide at five-minute intervals, 24 hours a day. Meterological parameters measured are wind speed, wind direction, and ambient temperature.

TEXAS AIR CONTROL BOARD ORGANIZATION CHART


GOVERNOR
TEXAS AIR CONTROL BOARD
Hearing Examiner
Executive Assistant
Executive Director
Legal
Regional Offices
Control and Prevention Program
Measurements and Analysis Program
Standards and Regulations Program
Administrative Services Program
Compliance
Permits and Source Evaluation
Air Quality Surveillance
Laboratory
Abatement Requirements and Analysis
Control Strategy
Management Services
Data Processing
REGIONAL OFFICES
Abilene
Lubbock
Waco
Harlingen
Corpus Christi
Odessa
Houston
Fort Worth
San Antonio
Beaumont
El Paso
Tyler

The noncontinuous air monitoring stations (NCAMS) provide information on air pollution trends and patterns both from urban and rural locations throughout Texas, augmenting the CAMS network at a lower cost. This network is maintained by a regional staff and volunteer operators throughout the state and consists of 105 particulate samplers, 87 gas bubbler samplers, and seven dichotomous samplers. Each of these samplers operates for one 24-hour period every six days. Total suspended particles and lead in the ambient air are measured with a high-volume air sampler, which collects particulates by drawing air through a cellulose filter. The Board's Laboratory examines the cellulose filters, determines the particulate weight, and performs analysis for more than 30 elements and compounds found on or trapped in the filter. The gas bubbler samples nitrogen dioxide, sulfur dioxide, ammonia, aldehydes, and oxidants by pulling ambient air through liquid absorbers. Bubbler absorbers are sent to the headquarters for laboratory analysis.

The Texas Air Control Board conducted almost 20,000 air pollution investigations during 1976-78. The majority of these investigations required sampling to determine whether a Board regulation had been violated. In many cases when a violation was established, voluntary compliance was obtained or a petition requesting time to comply was submitted to the Board.

In an attempt to prevent further air pollution, the Texas Air Control Board carefully examines applications for permits to construct and operate new facilities that may emit contaminants into the air. Permits must be obtained prior to construction, and the applicant must demonstrate that the operation of the facility will not contravene the intent of the Texas Clean Air Act or result in violations of state or federal air quality standards.

AIR CONTROL REGIONS AND LOCAL PROGRAMS

The Federal Air Quality Act of 1967 provides for the establishment of air quality control areas. In Texas, there are 12 such areas. The Board has a regional office located in each of these areas to provide a closer working relationship with city and county governments and pollution sources. The regional offices investigate complaints, maintain an inventory of all air pollution sources, and assist in legal actions against pollution violators. They also maintain the ambient air monitoring sites and the high-volume and gas bubbler network. The regional offices are in Tyler, Houston, Beaumont, Corpus Christi, Harlingen, San Antonio, Odessa, Lubbock, Abilene, Waco, Fort Worth, and El Paso.

The federal government also provided funding for local air pollution control programs. These local programs inspect public and private property to determine if the Board's regulations are being violated. They also may enact local air pollution control ordinances. A local government may institute a suit for injunctive relief, civil penalties, or both, whenever it appears that any regulation has been violated within its jurisdiction. To provide an incentive for local enforcement, all civil penalties recovered in suits instituted locally will be divided equally between the state and the local government. In cases where an air pollution emergency requiring immediate action to protect human health or safety exists, the Board or its executive director, with the concurrence of the governor, may order the immediate reduction or discontinuance of contaminating emissions. These emergency procedures are coordinated by the Board's Emergency Action Center, which is responsible for mobilizing resources during an air pollution emergency condition. The Emergency Action Center was activated for 64 such accidental episodes during 1976-78.

A more predictable type of air pollution episode is an Air Stagnation Advisory. The episode results from an areawide high pressure temperature inversion. Air Stagnation Advisory episodes usually result in the building up of pollutants and are monitored closely by the Board's sampling network. In 1976-78, there were approximately 19 air stagnation advisories issued by the National Weather Service.

In August 1977, Congress passed far-reaching changes to the Federal Clean Air Act. These amendments have stirred considerable public interest in the effect they may have on the nation's air quality and economy, and their implementation will require extensive action by the Texas Air

Control Board. In some regions of the state, the Act requires a substantial commitment by local governments to plan for and implement transportation controls for the purpose of improving air quality in that area.

In addition to responding to the 1977 Amendments, the Board is studying problems that may be created by future industrial activity, transportation systems, and other aspects of a changing civilization. These include such matters as the possibility of large-scale conversion to fuels higher in sulfur content, the increased number and changes in design and performance of automobiles, and the effect of mass transit systems. With proper planning, these changes can take place without creating additional air pollution problems. Thus, the people of Texas can enjoy the benefits of industrial growth and other changes in our social structure without having to endure polluted air.

Forest Resources of Texas

Trees mean many things to many people. To forest industry personnel, a tree is the raw material for making lumber, paper, poles, cross ties, and numerous other products. Sportsmen and women think of woodlands as homes for wildlife and places to hunt and fish. Urban residents consider wooded areas delightful recreation sites for camping, hiking, birdwatching, or family picnicking. Texas forests serve varied purposes without sacrifice of their economic value.

FORESTS SERVE PEOPLE

Gone are the days when forests were used exclusively for commercial timber production. That practice is being replaced by the concept of multiple use. Proper management of a forest for timber production also can provide food and cover for wildlife, protection for soil and water resources, and opportunities for outdoor recreation.

A look at the interdependence of trees, soil, water, air, wildlife, and humans provides an understanding of the significance of forests.

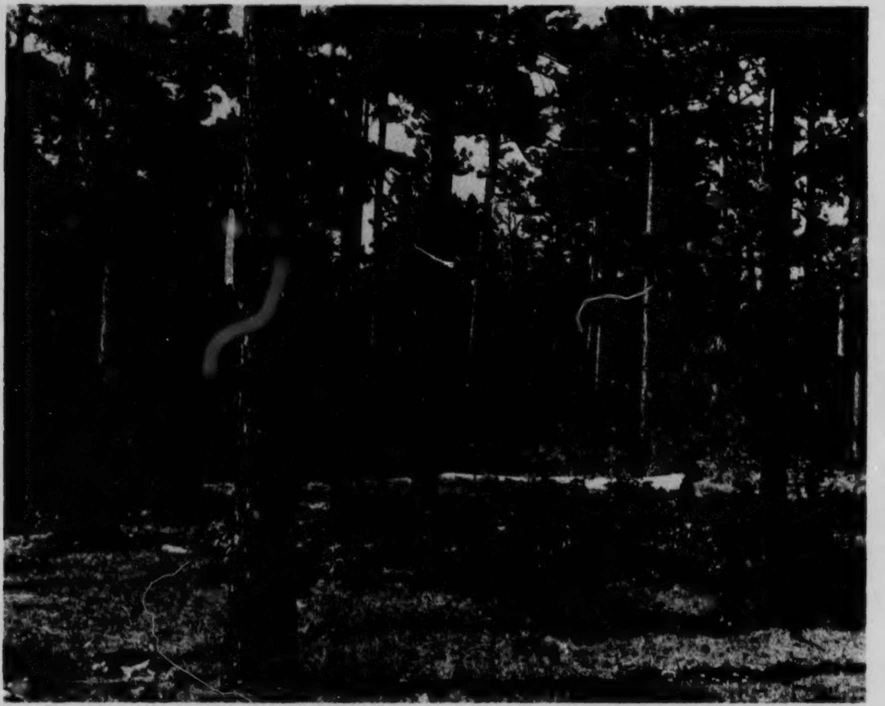
Trees are a renewable crop of the soil and to some extent a soil-renewing crop. A continual source of organic matter in the formation of new soil, decaying leaves and twigs, return nutrients to the soil and help it absorb and hold water. Working like a sponge, most forest soil can absorb and hold 226 tons of water per acre at any one time. Tree roots hold soil particles together, and the millions of tiny roots and root hairs also create channels for water and air.

A big tree is like an umbrella, intercepting the sun's rays on a hot day. During a rain, water moves over and around countless leaves and twigs before it finally drops to the ground. Hours after rainwater ceases to drip from trees, water is still filtering through the organic matter beneath them. This filtering system is why forest streams have a steady flow of clear water.

Windbreaks have a dual role in reducing soil erosion and protecting farmsteads from the hot summer winds and cold winter storms. Wind speed can be reduced by up to 80 percent behind a good windbreak. During the summer months, this means a significant decrease in the drying out of the soil. A winter chill temperature of 32°F could be reaised as much as 15°F behind a windbreak. Chinese elm, Austrian pine, catalpa, mulberry, honeylocust, Russian olive, osage orange, redcedar, and other tree species are planted in windbreaks. Trees for this purpose can be purchased from the Texas Forest Service.

Trees act as recycling plants for our atmosphere. While consuming almost six tons of carbon dioxide per year, an acre of young, vigorous growing trees produces four tons of oxygen. As much as 60 percent of other noxious gases such as ozone, sulfur dioxide, and nitrogen dioxide are removed from the air by trees. In tree-covered urban areas as much as 80 percent of the dust in the air is removed by the leaves of trees.

A good wildlife habitat includes food, cover, and water. Several species of animals can usually share the same land because their food and cover requirements are different. Tree squirrels are abundant only in the woods; whereas waterfowl, muskrat, and fish must have an aquatic environment. Most wildlife species prefer a mixed land-use pattern that includes forest, cropland, and grassland. Texas has large areas of such land. People need forests for many reasons. Enough lumber and wood products are used each year in America to lay 1" X 12" planks from here to the moon. A Sunday edition of a typical Dallas or Houston newspaper requires over seven acres of trees to produce. And while the demand for wood products continues to increase, so does the demand for the many other uses of our forests. Demand for land and space for outdoor recreation is increasing at the rate of 40 percent every 10 years. Urban sprawl and population growth are becoming increasingly important factors that affect the utilization, management, and growth of forest resources. This is especially true along the Gulf Coast. These pressures are gradually reducing the area of forest land. The same pressures are increasing the multiple use of the remaining forest lands.



Good forest management results in healthy trees and a groundcover of well-balanced vegetation.

TREE REGIONS OF TEXAS

"Texas is the battleground for supremacy of the plant races," said the late William Bray, one of Texas' outstanding botanists, after a survey of the forests in 1904.

Parts of three of the six main forest regions of the United States are found within the boundaries of this vast state. The Southern Forest Region extends into the extreme eastern part of the state. These forests are an extension of the southern pine belt. Species found in the Central Hardwood Forest Region are also found in the Post Oak, the East and West Cross Timbers, and the miscellaneous forests of Texas. Forest growth typical of the Rocky Mountain Forest Region is found on the tops of the higher mountains in West Texas. Although not considered a major forest region in Texas, three species that thrive in tropical climates are found in the southern tip of the state.

Fighting heat, drought, and winds and adapting to different types of soil, many trees that are common to other sections of the country have, through the ages, developed into well-established Texas varieties. Mountain cedar, Texas walnut, mountain live oak, Texas redbud, and woolly buckeye—all common to the Edwards Plateau—are close kin to Eastern redcedar, black walnut, live oak, Eastern redbud, and Ohio buckeye of the more humid regions.

The battle of adaption has given Texas almost 800 kinds of woody plants growing on an estimated 23.4 million acres of forest land. This figure does not include extensive areas of mesquite and other small woody growth.

Mesquite is the most conspicuous plant on several million acres in the Rolling Plains of west central and northwest central Texas. The area it occupies is not recognized as a tree region and is more suitable for rangeland. Extensive eradication of mesquite in recent years has greatly reduced the acreage.

Of all the factors that determine the pattern of the state's tree growth, moisture plays the most important part. This moisture may be derived from rainfall, or it may be the amount of moisture that the soil holds. In the eastern part of the state with almost a 50-inch annual rainfall, the pines and hardwoods grow tall. In Central and West Texas, a 15- to 20-inch annual rainfall area, some oaks are not over knee high. They form the oak shinneries, the "pygmy forests" of the state.

Geological formation, soil quality, and other natural factors also affect the pattern of tree growth in Texas. All of Texas' forest regions, with the exception of the Mountain Forests, lie east of the 100th meridian, used by geographers to separate the eastern from the western life zones. The eastern line of the Panhandle follows the 100th meridian.

Pine-Hardwood

The Pine-Hardwood region covers approximately 19.4 million acreas in 37 counties in the extreme eastern portion of the state. This Texas forest region, often called the Piney Woods, has been the center of commercial timber production for more than a century. Standing timber volume is estimated at 11.8 billion cubic feet or enough wood to build 5.5 million new houses.

The native pines in the Pine-Harwood region are loblolly, short-leaf, and longleaf. Commercially, loblolly pine is the most important tree species.

High-grade hardwoods grow along many East Texas streams.

In much of the Piney Woods, hardwoods intermingle with pines, particularly on the uplands. Hardwoods dominate the lowlands adjacent to some of the major East Texas streams. The principal hardwood species in the Piney Woods are red, black, and tupelo gums; white and black oaks; magnolia; elm; hickory; walnut; maple; beech; white ash; and bald cypress.

Climate and soils of the Piney Woods are more favorable to trees than to most farm crops. The average temperature is 65°F, and the average length of the frost-free period is 240 days per year.

The characteristic topsoils are light-colored sandy loams and loamy sands. Subsoils range from loamy sand to plastic clay in texture and from yellow to red in color. The soils are medium to strongly acid and are generally low in all essential plant nutrients. Some of the depleted cropland in forest clearings has been reforested by natural reseeding. There is some productive cropland in the lowlands that is not flooded frequently.

Contrary to popular belief, land ownership in the Piney Woods is not confined to a few large landowners. Public ownership, almost entirely in national forests, accounts for 7 percent of the total commercial forest acreage. Private nonindustrial owners control 59 percent, and industry owns 34 percent of all East Texas forest land. Small tracts, owned by farmers, ranchers, and others, generally are not intensively managed.

Public and industrial forest lands typically support more dense stands of trees than do private, nonindustrial holdings. On public lands, for example, growing trees average about 1,595 cubic feet of wood per acre. Forest industry holdings support about 1,172 cubic feet of wood per acre. By contrast, private nonindustrial ownerships only average about 905 cubic feet per acre. Productivity on private nonindustrial land is low. This is attributed to poor land management and the need for reforestation.

A number of forces are operating to change the net area of forest land in East Texas. In some areas, these forces tend to increase the forest land area; in others, they reduce it. Most of the forest acreage losses are due to construction of water reservoirs; development of right-of-ways for highways, roads, and utility lines; urban expansion; and development of recreational areas.

The future of commercial forestry to East Texas is in the hands of private, nonindustrial owners who hold nearly two-thirds of the forest land in the area, as well as half the present timber inventory. These forest lands offer many possibilities for improving the timber resource through intensified management. Such management efforts have attracted new wood-using industries and are encouraging expansion of existing ones. Establishment of the multimillion dollar pine plywood industry in East Texas and expansion of the pulp industry, for example, were largely related to gains in Texas' timber inventory. The importance of the forest resource to industrial development in East Texas provides a strong incentive for further improving timber productivity.

The Post Oak region is an area of low rainfall and frequent periods of drought.

Post Oak

This wooded region of Texas has approximately 3,612,000 acres of trees in all or parts of 26 counties.

Soils in the Post Oak region are similar to those found in the Piney Woods; however, a greater proportion of the soils are prairie soils that are less acid. Uplands comprise 85 percent of the region; bottomlands, 15 percent.

Tree species in the Post Oak region include post oak, hackberry, elm, pecan, live oak, ash, and hickory. The better quality trees are found in the bottom lands. The 166,000 acres of loblolly pine found in Bastrop, Caldwell, Colorado, Fayette, and Lee Counties, located in the southwestern end of the Post Oak region, are referred to as the "Lost Pines of Texas."

Fence posts, cross ties, bridge decking, firewood, and some lumber and pulpwood are the principal wood products in the Post Oak region.

The average annual precipitation is 35 to 45 inches. With the exception of precipitation, the climate of the Post Oak region is much like that of the Pine-Harwood region.

The exact wood volume and value of the East Texas and West Cross Timbers regions are still unknown.

East and West Cross Timbers

The East Cross Timbers is a long strip of wooded land that separates the Blackland from the Grand Prairie. Having a width of only a few miles, this area of about 190,000 acres extends from the Red River southward into Hill Country.

West Cross Timbers is a wooded section of the Grand Prairie in north central Texas. The area extends from the Red River southward into Coleman and Brown Counties.

Having a total area of approximately 2,226,000 acres, the East and West Cross Timbers have soils that are similar in color, texture, and structure and are low in fertility. The topography of the Cross Timbers is more rolling than that of the Post Oak region, and it has a lower average annual precipitation of 25 to 35 inches.

Post oak and blackjack oak occur in most of the region. Pecan, cottonwood, elm, and other hardwoods grow along the streams. Fence posts and firewood are the principal wood products of the region. No survey has been made to determine the volume of marketable timber.

The Cedar Brakes region contains mountain cedar, redberry juniper, and live oak as the principal species.

Cedar Brakes

Mountain cedar is the dominant tree growth of this hilly region of about 4,561,000 acres in east central Texas. From the western edge and southern end of the Grand Prairie, the Cedar Brakes region extends southwestward into the Burnet-Llano Basin and onto the Edwards Plateau. Much of the cedar grows in mixed stands with oak, elm, sumac, and other tree species. The average annual precipitation in the Cedar Brakes is 20 to 35 inches.

Over much of the Cedar Brakes, a thin, stony, calcareous soil has developed from limestone and marl. Alluvial soils occur in the flood plains of streams.

Fence posts are the principal wood product of the region. Other products include cedar oil, fencing, cabinet lumber, novelties, and firewood.

Mountain Forests

The Mountain Forest region covers approximately 347,000 acres in west Texas. Most of this tree growth is in Jeff Davis County; however, it is also found in Brewster, Culberson, and Presidio Counties. The soils are generally shallow, stony, and nonarable; however, some are moderately fertile. Short grasses and shurbs are the characteristic vegetation in the basins and valleys. The mountainous lands are covered with juniper, piñon pine, several species of oak, and scattered specimens of western yellow pine and Douglas fir. Most of the timber is found on mountain crests. Annual precipitation averages 10 to 15 inches.

The major species in the Mountain Forest region include piñon pine, western yellow pine and Douglas fir.

Coastal Forests

The Coastal Forest region covers approximately 575,000 acres extending from Galveston County westward to the Lavaca River in Jackson and Calhoun Counties. The principal tree species found in this area are water, willow, live and post oaks, pecan, ash, hackberry, cottonwood, sycamore, black willow, and some loblolly pine.

Clay soils are extensive throughout the region. Dark gray to reddish-brown calcareous silt loams, clay loams, and clays are found in the bottomlands where the majority of the wooded areas are located. The topography is generally flat, and drainage is poor.

The region has a modified maritime climate characterized by a mean annual temperature of 69 degrees and a mean annual precipitation of 45 inches.

Coastal Forests are located in parts of Harris, Galveston, Fort Bend, Brazoria, Wharton, Matagorda, Jackson, and Calhoun Counties.

Miscellaneous Forest

The area extending westward from the drainage of the Lavaca River to the drainage of the Nueces River, west of Uvalde, contains a forested area of approximately 774,000 acres. The vegetation is characteristic of the warm, dry Rio Grande Plain.

The principal tree species found in this region are live oak, cedar, elm, hackberry, and bald cypress. Other tree species include sycamore, ash, and mulberry. The stands of timber are generally considered to be unmerchantable, although some large and impressive trees may be found there.

COMMERCIAL FORESTS AND FOREST INDUSTRIES

Most of the public's interest in wise use of the nation's forests has developed in the short span of two generations. National and state forest conservation programs that began to evolve early in this century have had their greatest growth since 1930. By the time Americans began talking about forest conservation, forestry had been practiced in Europe for more than a century. European experience in forest management had already demonstrated that forests improved with use. In fact, it had been found that forests deteriorate under nonuse but reach maximum productivity under a program of planned harvesting. Through forestry, humans work with nature so that there will be a continuous replacement of trees that are removed.

All Texans benefit from the practice of forestry on commercial forest lands. With proper management, the productive capacity of these lands increases to meet the growing needs of people. This adds up to greater income for the timberland owner, continuous employment opportunities for workers engaged in harvesting and processing timber, and more wood products for expanding markets. It also encourages the establishment of new permanent forest industries and broadens the tax base thus reducing the tax burden of individuals.

The production of Texas timber, particularly pine, can be increased if adequate protection is provided from forest pests and wildfire through prevention and control. The amount of timber destroyed by fire, insects, and disease is excessive. The southern pine beetle in East Texas alone caused an estimated loss of $17 million in timber value in 1976. The prevention and control of wildfires and pests require cooperation of the public and landowners. The public, mostly through carelessness, is responsible for about 99 percent of forest fires in Texas.

Increased timber production can also be realized through proper forest management on privately owned lands. This is particularly true on the approximately 62 percent of the land that is owned by small, nonindustrial landowners. The use of correct harvesting techniques and reforestation can increase production.

The Pine-Hardwood region of Texas covers approximately 19.4 million acres, 93 percent of which is privately owned. Fifty-six percent (11 million acres) of this region is capable of growing trees for commercial use. The Piney Woods area of East Texas sustains more than 170 wood processing industries whose 151,000 employees receive annual wages in excess of $394 million. Forest industries directly and indirectly contribute well over $5 billion to the Texas economy annually.

Texas' forest industries are dependent upon the proper management and protection of this vital, naturally renewable resource that contributes so much to the state's economy.

Future growth and expansion of Texas forest industries will depend upon an adequate supply of timber. This can be realized only if large and small private landowners accept their responsibility to adopt high standards of forest management. It is equally important for the public, through the state forestry agency, the Texas Forest Service, to provide reasonable protection from wildfires and forest pests. This agency also provides assistance to landowners who want to get maximum economic and related benefits when they adopt and use good forestry practices on their land.

Trends in the use of Texas timber have changed during the past decade. Sawlog production accounts for about 25 percent of the total timber harvested while an expanding pulpwood industry uses about 60 percent of the timber. Here, as in other southern states, the percentage of timber harvested for pulpwood is well above the national average. Other major uses of Texas timber include: veneer and plywood, 15 percent; poles and piling, cooperage, cross ties, and other products, less than one percent.

In Texas, the use of over half the annual timber harvested for pulpwood; expansion of the veneer and plywood industry; and the decreasing use of wood for lumber follows the general pattern of wood utilization for the South.

Volume growth within Texas forests, no longer exceeds the total volume harvested each year. In 1978 the net annual growth of pine timber in Texas forests for the first time was less than the amount harvested. (See Table 1.) Increased demand and prices for timber should provide more incentive to large industrial forest landowners and to the nonindustrial landowner to manage their land more intensively. This should increase the growing stock and will have a definite expansion effect on future growth of Texas forests. The small, nonindustrial landowner is the key to meeting the needs of a growing demand for forest benefits and wood products.

Table 1. ANNUAL GROWTH AND HARVEST OF GROWING STOCK IN EAST TEXAS, 1964-78

		Million Cubic Feet		
Year	Species group	Growth	Harvest	Harvest as percent of growth
1964	Pine	405.2	199.3	49.0
	Hardwood	95.3	99.9	105.0
1969	Pine	442.1	304.6	69.0
	Hardwood	92.0	81.5	88.0
1974	Pine	469.6	379.4	80.8
	Hardwood	210.6	95.1	45.2
1975	Pine	458.4	389.3	84.9
	Hardwood	208.5	72.6	34.8
1976	Pine	461.2	432.8	93.8
	Hardwood	215.7	80.6	37.4
1977	Pine	461.9	453.9	98.3
	Hardwood	201.1	89.1	44.3
1978	Pine	467.6	475.4	101.7
	Hardwood	205.9	103.1	50.1

Research on forest products is pointing the way toward more efficient utilization of wood. Over 85 percent of the wood residues that once were treated as waste in manufacturing processes is now being used by the forest industry. Scientists may develop products that can substitute for present wood uses, but people are also increasing the need for more trees by finding new uses for wood.

Wildlife Resources of Texas

Wildlife resources of Texas are among the most abundant in the Unites States. A broad definition of wildlife might be all animals except humans and their domesticated animals that live in a natural environment.

Wildlife resources can be divided into game and nongame species of vertebrate animals and of nonvertebrate forms such as shrimp, crabs, and oysters.

An animal can only be designated as a game animal by an act of the legislature. Game animals are then managed and protected, if necessary, for the good of the species and of the habitat.

GAME MAMMALS

The animals designated as game mammals in Texas are white-tailed deer, mule deer, pronghorned antelope, elk, javelina (collared pecarry), red (fox) squirrels, gray (cat) squirrels, aoudad sheep (in certain Panhandle counties only), black bear, and desert bighorn sheep. Of these, only the aoudad sheep is a nonnative.

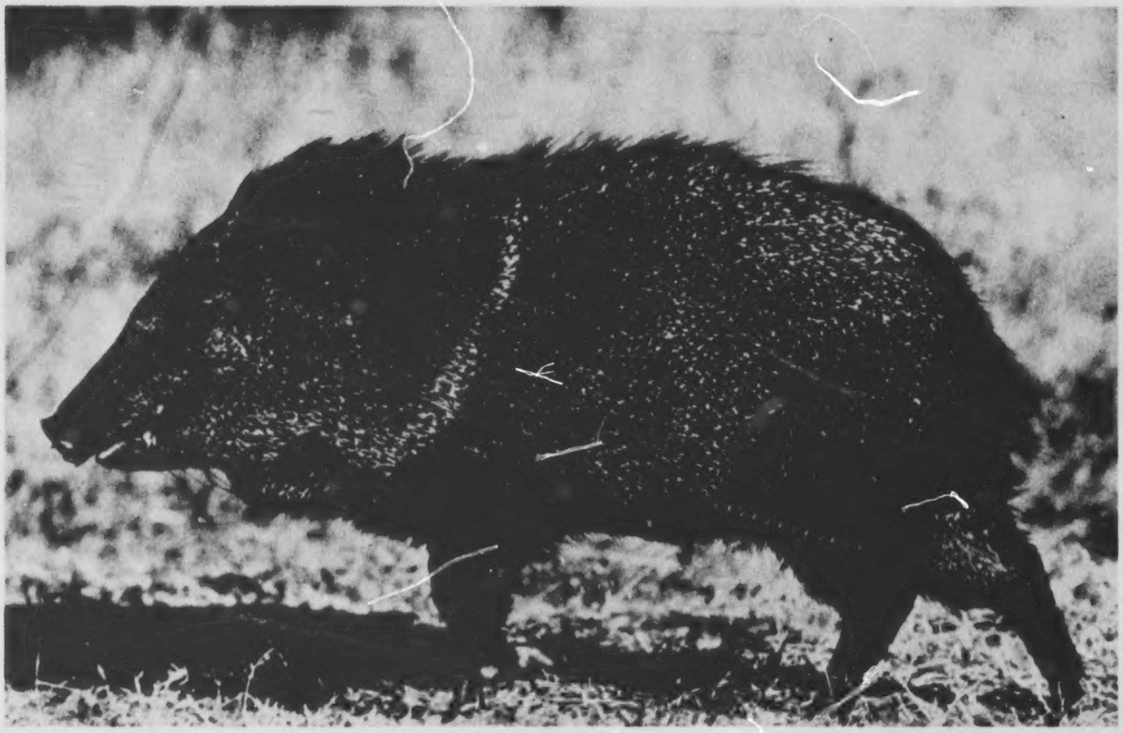
White-tailed deer are the most widely distributed of the big game animals occurring in huntable numbers in most Texas counties. Mule deer are found in the Trans-Pecos, Panhandle, and other western areas of the state.

Healthy white-tailed buck deer abound in the Hill Country.

Prong-horned antelope occur primarily in Trans-Pecos and Panhandle counties. Elk, in huntable numbers, are confined to the highest vegetated mountains in West Texas. Special seasons for hunting elk have been permitted; however, because of the lack of suitable habitat in Texas, it is doubtful that the elk population will ever provide much sport for hunters.

Javelina are numerous in the South Texas brushlands, their range extending to the Trans-Pecos and Edwards Plateau areas of the state.

Black bear are rare. Apparently they have been extirpated from the Big Thicket area, their last stronghold in East Texas. A few can still be found in the mountainous areas of West Texas.

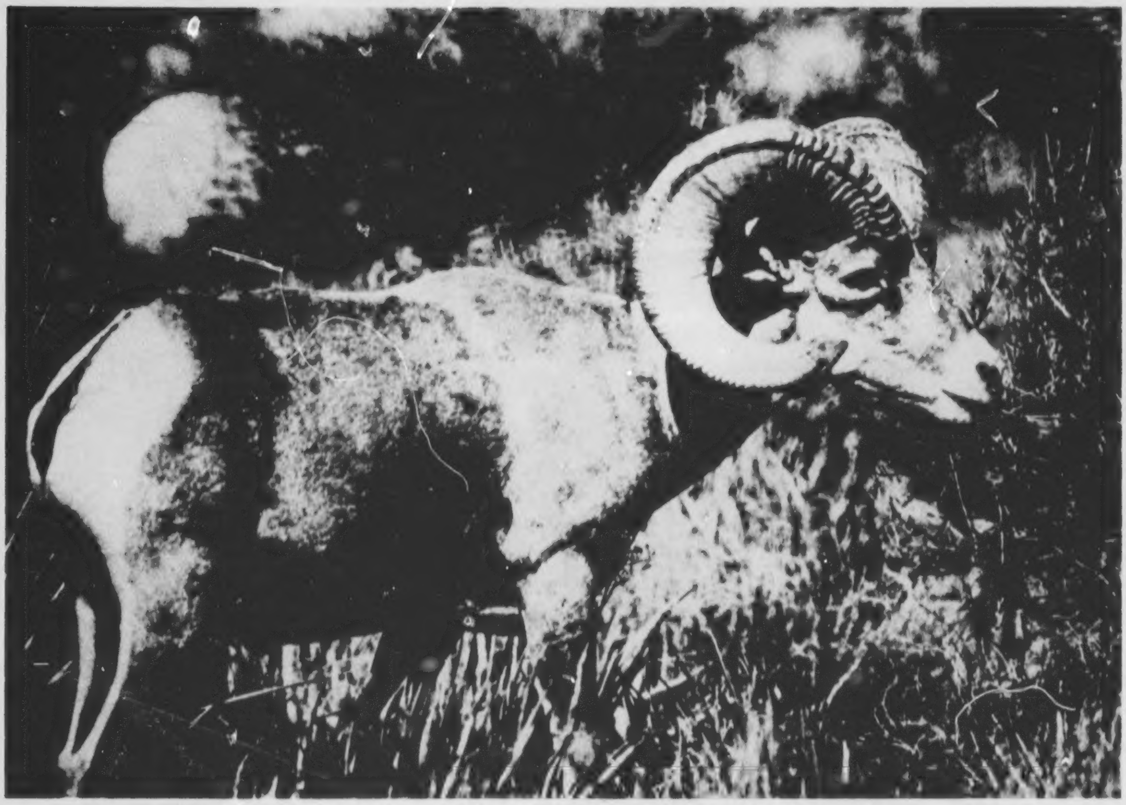


A herbivore, the javalina is a piglike animal found in South Texas.

Squirrels are popular game mammals in East Texas. The gray squirrel prefers bayous, creeks, and river bottoms of East and Southeast Texas. Its range is restricted to these areas. The larger fox squirrel may be found throughout the eastern two-thirds of the state.

Aoudad sheep and other introduced exotics, such as axis deer, black buck antelope, and fallow deer have been imported by numerous ranches and private game preserves. As their populations grow, they are spreading into larger areas. Aoudads were introduced in the Palo Duro Canyon area by the Parks and Wildlife Department. Indications are their numbers are increasing and that controlled harvesting, begun in 1963, will continue.

The original desert bighorn sheep herds have disappeared from Texas. A restoration program, designed to re-establish the desert bighorn, is underway by the Parks and Wildlife Department on the Department's Black Gap Wildlife Management area in the Big Bend National Park.



The desert bighorn sheep in the mountains of West Texas is considered a rare and endangered species.

GAME BIRDS

Game birds may be divided into resident and migratory forms. All migratory birds, game and nongame, are protected by the federal government under international treaty agreements.

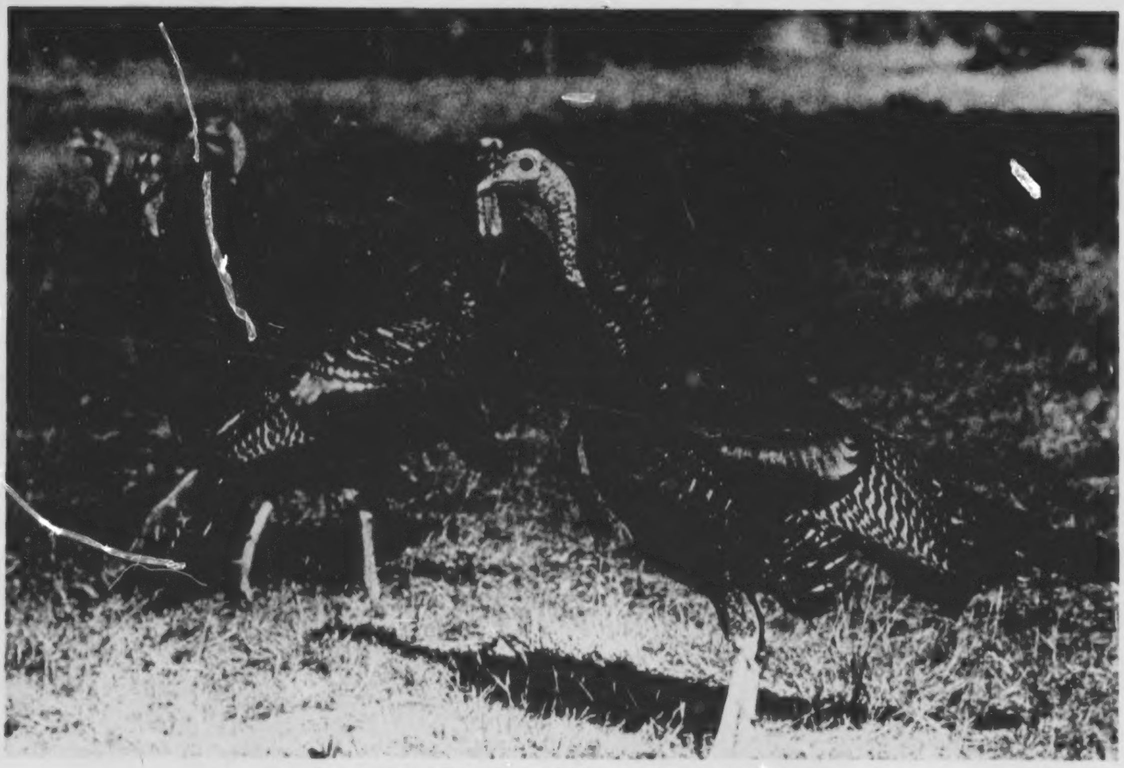
The bulk of the waterfowl that migrate on the Central Flyway winter in Texas. They follow the watercourses from as far as Canada and Alaska to their winter homes in the state's wetlands.

Many species of ducks, geese, and brant with the less-popular coot or mud hen make up the bulk of Texas' migratory waterfowl. Two species of cranes winter in the western regions and coastal areas. Woodcock, Wilson's (Jack) snipe, rails and gallinules winter in the wetlands. Woodcock are also found in the eastern portion of the state along sandy creek bottomlands and in timbered areas near marshes and swamplands.

Statewide, the mourning dove has the largest population and provides more days of recreational hunting than any other migratory game bird. When the white-winged dove migrates into the Rio Grande Valley, one of the state's most popular and shortest (usually one or two weekends) hunting season is open. The rapid conversion of native brushland in the Rio Grande Valley to agricultural land threatens to decrease nesting habitat for the white-winged dove in Texas.

Texas has more wild turkeys than any other state. Turkeys are not migratory birds; however, they do make seasonal movements. Their range extends from the Panhandle through the center of the state and the Hill Country to the Gulf Coast and Rio Grande brushlands. Rio Grande turkeys have been known to use the same roosting area for over 100 years.

As a result of uncontrolled market hunting at the turn of the century, the population of the eastern turkey, which lives in the Piney Woods in East Texas, is very low. Recently, the Parks and



Rio Grande wild turkey gobblers feed in an open area.

Wildlife Department began a restocking program with birds imported from Florida and the Carolinas. There are indications that they may become established in huntable numbers in the area again. Experiments are in progress on a hybrid Rio Grande/eastern wild turkey to inhabit the area between the ranges of the two species.

Merriam turkeys, often called mountain turkeys, can be found in the Guadalupe Mountains along the Texas-New Mexico border.

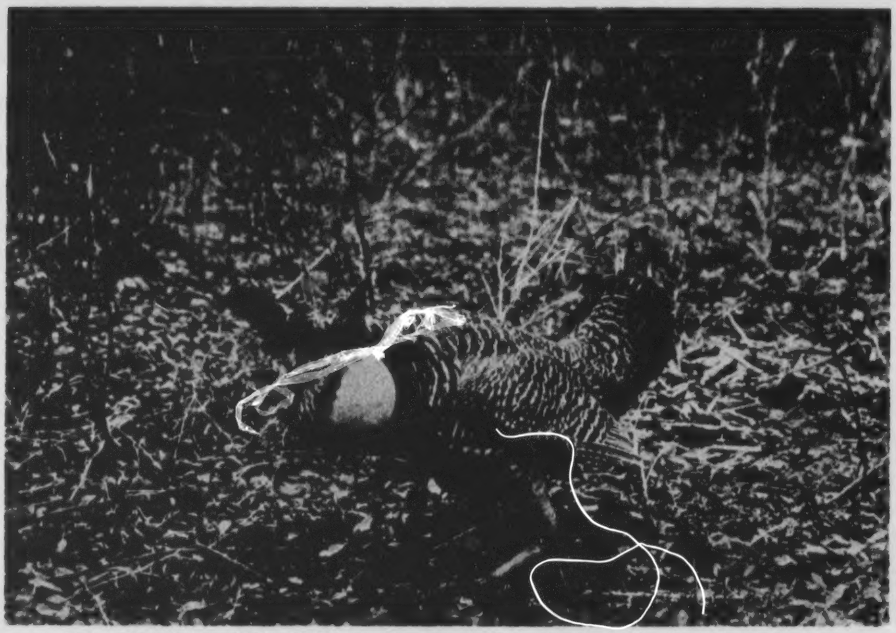
The bobwhite is the predominate quail species in Texas. Bobwhites are found in the eastern and central areas with an annual harvest of between four million to six million birds. Scales or blue quail range in the western part of the state. Along the eastern edge of their range, usually considered to be the 101st meridian, they intermingle with the bobwhite. Both species afford excellent sport for hunters. Sport hunting has little effect on quail populations because there is an 80 percent loss due to natural causes each winter.

Mearns' (Harlequin) and Gambel's quail, native to the Trans-Pecos region, are founded in limited numbers. The season on Mearns' quail has been closed for a number of years.

Wild pheasants in huntable numbers are found in areas of the Panhandle. Pheasants of different species have been experimentally released in various regions of the state to determine if stable populations of these desirable game birds can be established. Results have been very good in some coastal areas, and flocks are expected to reach huntable proportions soon.

Chachalacas inhabit brush thickets in the lower Rio Grande Valley. These olive-green birds are often called Mexican pheasants or tree pheasants.

Two species of prairie chickens are found in the state. The lesser prairie chicken is found in the Panhandle. Market hunting at the turn of the century decimated the flocks, but with proper management they now exist in sufficient numbers to allow a brief season in some Panhandle counties. The endangered Attwater's species inhabits certain grassland prairies on the Gulf Coast. Because of habitat loss and their inability to adapt, Attwater's prairie chickens have not responded to management. They are classed as game birds; however, the season was closed, and they have been protected by state and federal laws for a number of years.



Male Attwater's prairie chicken performs courtship dance on the booming grounds.

FOOD AND GAME FISH

Texas fish may be divided into two groups: freshwater fish (inland waters) and saltwater fish found in estuarine areas and the Gulf of Mexico.

Among the most popular of the native food and game fish in inland waters are the largemouth bass, spotted bass, crappie, channel catfish, flathead catfish, and numerous sunfish including bluegills, redears, and goggle eyes. Although the carp, drum, and buffalo are edible, they have not gained a high degree of popularity.

Texas has more constructed reservoirs that can be used for recreational purposes than any other state, with only one natural lake (Caddo Lake). Native game fish evolved as stream and river fish. The large open-water impoundments are not their usual habitat and native predator fish such as largemouth bass occupy only the periphery of the huge lakes. The open portions are virtually empty of game fish and in some cases glutted with forage or rough fish such as shad.

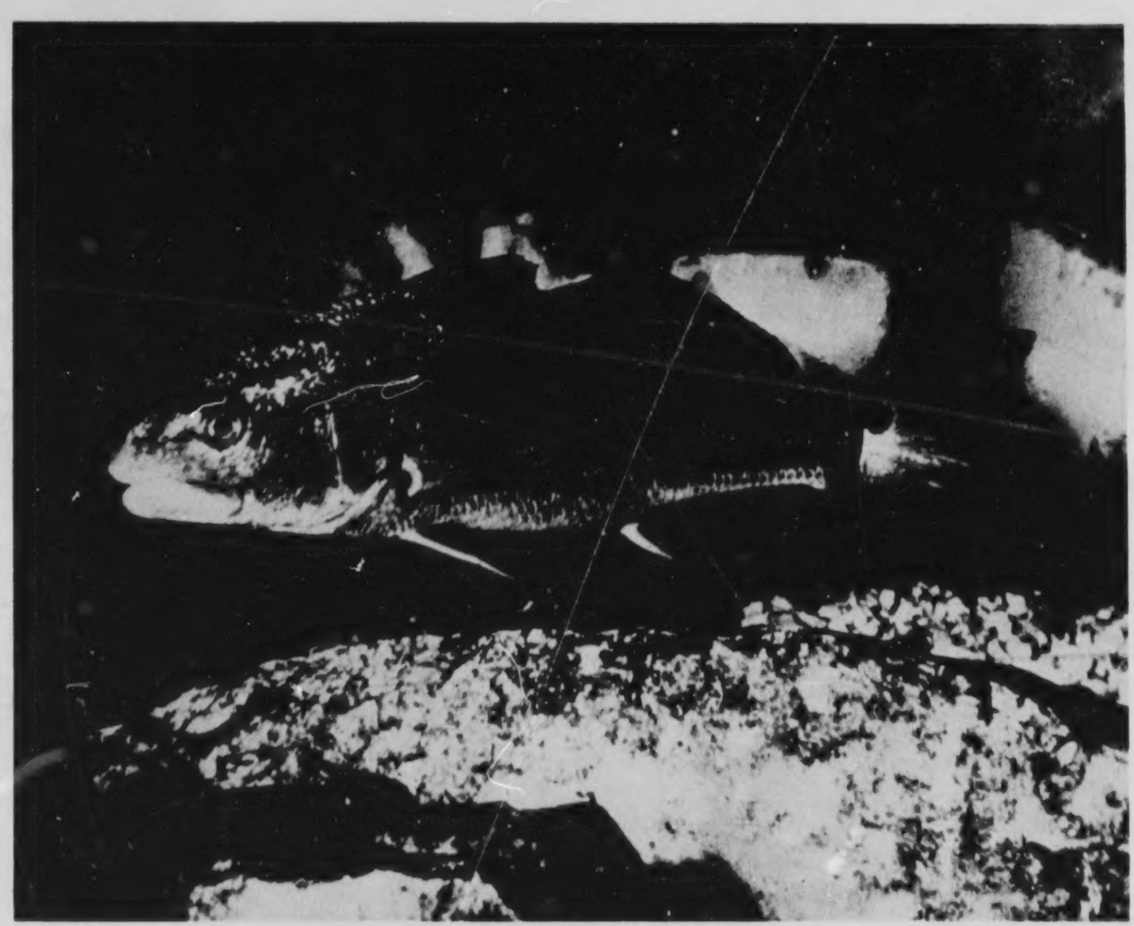
Large game fish that cruise the open waters are needed to control rough fish populations and also provide sport for anglers in the middle of the lakes.

Walleye, smallmouth bass, Florida bass, northern pike, and muskellunge from other states have been stocked in Texas lakes, and these fish are being raised in Texas hatcheries.

Saltwater fish such as striped bass, redfish, speckled sea trout, and southern flounder are being experimentally stocked in some inland lakes and in some cases the growth rate is high.

Experiments are in progress on fish from other continents to see if they are suitable for Texas reservoirs. The most important of these are the African Nile perch and South American peacock bass.

An extensive program of hybridization is underway. Florida largemouth bass are being crossed with native bass and the results are called "superbass." There are also white/striped/bass hybrids and northern pike/muskie hybrids that are showing good results.



Redfish is a saltwater game fish.

Rainbow trout are being raised in hatcheries of the Texas Parks and Wildlife Department and stocked where the water is colder than average in Texas. Conditions are not right for reproduction, but a put-grow-and-take program has been established by the Department on the lower Guadalupe River below Canyon Dam and on the Brazos River below Possum Kingdom.

In the saltwater group of food and game fish, the speckled trout, redfish, flounder, sand trout, sheepshead, golden croaker, and drum rate high with the bay anglers.

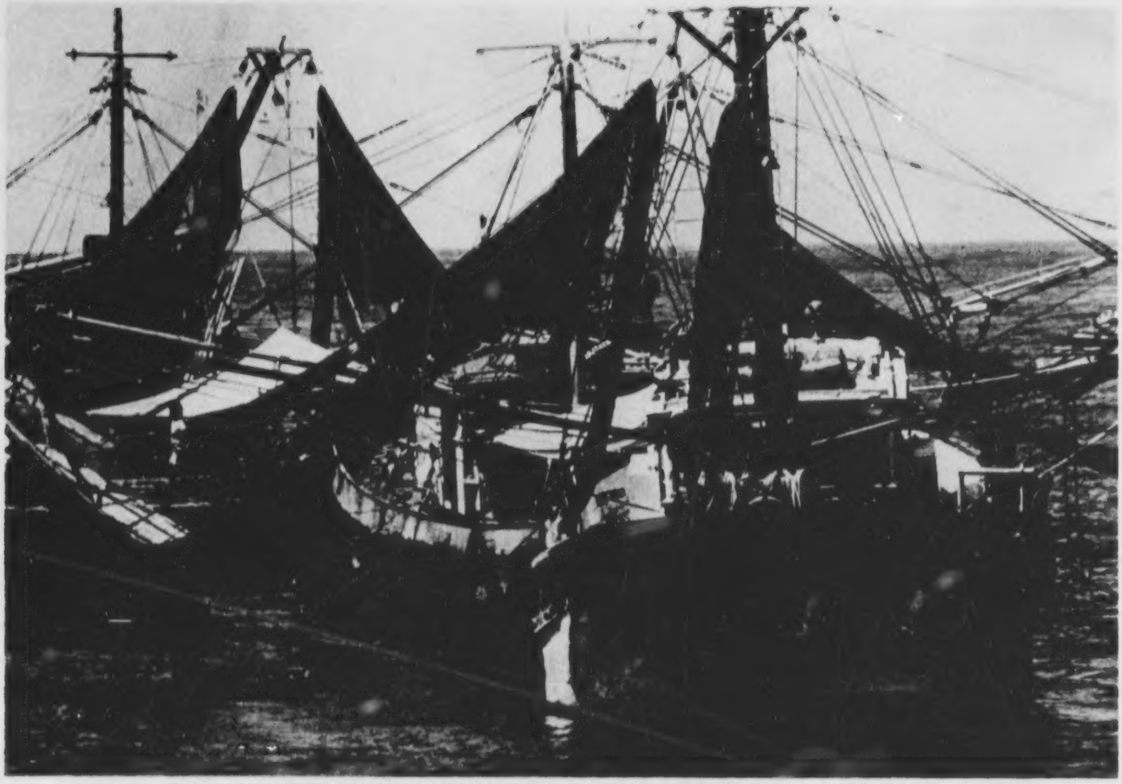
Spanish mackerel, kingfish, red snapper, grouper, jewfish, and ling are favorite offshore Gulf fish. Some species such as pompano and Gulf whiting are considered choice food fish and a small number of them can be found in Texas' waters.

Texas has no closed season on sport fishing in its public waters. It has perhaps the most lenient fishing licensing program of any state.

OTHER IMPORTANT FORMS

Marine

Among other forms of marine life that are of economic importance to Texas are shrimp, oysters, crabs, and menhaden.



Nets are spread to dry on Gulf shrimpers at Port Isabel before another fishing run.

Texas leads the nation in shrimp landings. It is one of the leading oyster-producing states and has a young but growing blue crab fishery.

Processing plants have been established in several coastal areas to utilize menhaden, a rough fish, in the production of oils, animal feeds, and fertilizer.

Amphibian

Of the amphibians found in Texas, the southern bullfrog is perhaps the only one of measurable economic importance. Frog legs are served as delicacies in many restaurants.

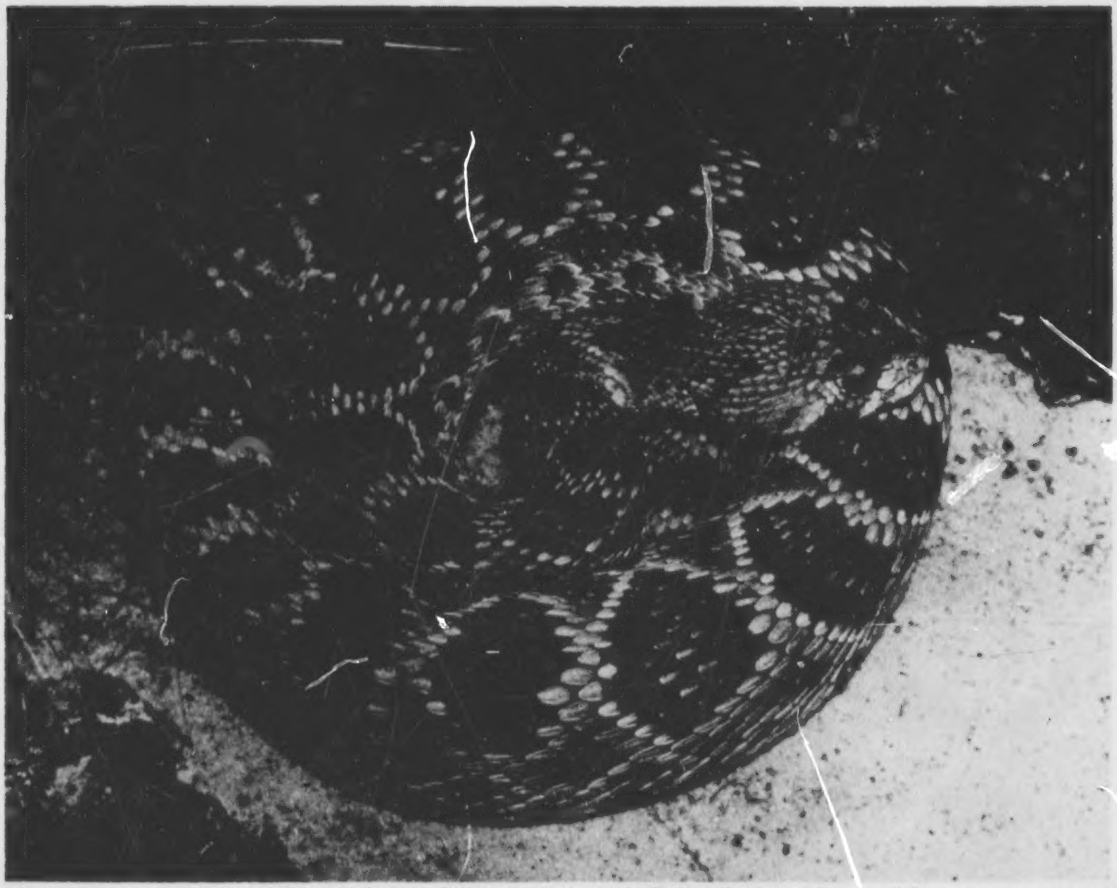
Reptiles

The largest reptile found in Texas is the alligator. The American alligator is on the endangered species list and is protected by both federal and state laws.

The alligator has responded well to protection, and in some areas there is a surplus of alligators. When an alligator becomes a nuisance to humans, Parks and Wildlife Department personnel capture it and move it to a less-populated area.

All four kinds of poisonous snakes found in the United States live in Texas: rattlesnakes, coral snakes, copperheads, and water moccasins.

Soft-shelled turtles, diamond-backed terrapins, and other turtles, including some marine forms, may be utilized as food. The horned lizard (horned toad), Texas tortoise, sea turtle saltwater terrapin, and green turtle are protected by Texas statutes.



The western diamond-back rattlesnake is one of three vipers found in Texas. The copperhead and the water moccasin are pit vipers.

NONGAME ANIMALS

Only a few of the 138 species of mammals found in Texas are classified as game species. Furbearers, which have an economic value, are afforded some protection by state law. The furbearers include the muskrat, mink, beaver, otter, badger, ringtail, skunk, raccoon, oppossum, and fox.

The red fox, ocelot, margay, and jaguar are predator animals on the endangered species list and are protected by both federal and state laws. Other predators such as mountain lions, coyotes, and bobcats are unprotected. Rodents, rabbits, and armadillos are unprotected and can be hunted at any time.

More than 540 species of birds have been recorded in Texas, most of which are protected under state and federal laws. In addition to the valuable game species, there are the endangered whooping cranes that winter along the coast at the Aransas National Wildlife Refuge near Austwell. Birds with limited range such as the golden-cheeked warbler, nest in the Hill Country; green jays and phainopeplas in the Rio Grande Valley; and roseate spoonbills in coastal marshes. These and others attract many birdwatching enthusiasts to Texas.

There are only two birds found in Texas that are not protected by state or federal laws: European starlings and English sparrows.

RARE AND ENDANGERED SPECIES

Recent ecological studies and environmental research emphasize the plight of many forms of wildlife. Habitat degradation and shrinkage, coupled with pollution of the environment, poses a far greater danger to wildlife than sport hunting and fishing.

Protective legislation to assure the survival of certain wildlife species has been passed. Under the federal Endangered Species Act of 1973 and the amended Texas Endangered Species Act of 1973, the following wildlife species are offered protection:

The whooping crane, which winters along the Gulf Coast near Austwell, is protected by state and federal law.

MAMMALS

Blue whale	*Balaenoptera musculus*
Finback whale	*Balaenoptera physalus*
Right whale	*Eubalaena spp.* (all species)
Sperm whale	*Physeter catodon*
Black-footed ferret	*Mustela nigripes*
Jaguar	*Panthera onca*
Margay	*Felis wiedii*
Ocelot	*Felis pardalis*
Red wolf	*Canis rufus*
West Indian manatee	*Trichechus manatus*
Bighorn sheep	*Ovis canadensis*

BIRDS

Brown pelican	*Pelecanus occidentalis*
Mexican duck	*Anas diazi*
Southern bald eagle	*Haliaeetus l. leucocephalus*
American peregrine falcon	*Falco peregrinus anatum*
Arctic peregrine falcon	*Falco peregrinus tundrius*

Attwater's greater prairie chicken	*Tympanuchus cupido attwateri*
Whooping crane	*Grus americana*
Eskimo curlew	*Numenius borealis*
Ivory-billed woodpecker	*Campephilus principalis*
Red-cockaded woodpecker	*Dendrocopos borealis*
Bachman's warbler	*Vermivora bachmanii*

REPTILES

Atlantic ridley turtle	*Lepidochelys kempii*
Hawksbill turtle	*Eretmochelys imbricata*
Leatherback turtle	*Dermochelys coriacea*
American alligator	*Alligator mississipiensis*

AMPHIBIANS

Cascade Cavern salamander	*Eurycea latitans*
San Marcos salamander	*Eurycea nana*
Fern Bank salamander	*Eurycea pterophila*
Texas blind salamander	*Typhlomolge rathbuni*
Houston toad	*Bufo houstonensis*

FISHES

Big Bend gambusia	*Gambusia gaigei*
Clear Creek gambusia	*Gambusia heterochir*
Pecos gambusia	*Gambusia nobilis*
Comanche Springs pupfish	*Cyprinodon elegans*
Fountain darter	*Etheostoma fonticola*

ROLES OF GOVERNMENT IN WILDLIFE MANAGEMENT

Since 1953, the Texas Regulatory Authority Act has given ever increasing responsibility for game management rules and regulations to the Parks and Wildlife Department. The Department was formed in 1963 by an act of the legislature which merged the former Game and Fish Commission with the State Parks Board. The Department has the authority to set and enforce seasons, bag limits, and means or methods of taking game in more than three-fourths of Texas' 254 counties. The Department also sets regulations for nongame animals, for the taking of oysters and shrimp, and for shell dredging. It establishes certain pollution laws and enforces the Water Safety Act.

The Parks and Wildlife Department has the reponsibility to obtain, build, restore, and operate state parks, recreational areas, historic parks, historic sites, historic structures, natural areas, and fishing piers.

The federal government maintains four national forests in East Texas that provide homes for wildlife. In addition to the Aransas National Wildlife Refuge, there are national wildlife refuges at Lake Texoma (Hagermann), Muleshoe, Laguna, Atascosa, and Anahuac. Big Bend National Park, Padre Island Seashore, and Guadalupe Mountains National Park serve as protected wildlife areas under federal control, as will the future Big Thicket National Preserve.

ECONOMIC VALUE OF TEXAS WILDLIFE

Anglers in Texas spent more than $39 million for rods, reels, lures, and lines alone in 1975. In the previous year, it was estimated that $660 million was spent on sports fishing in the state.

In 1978, the commercial fishing industry landed 104,130,740 pounds of fishers' products on the Texas Gulf Coast. These products had a dockside value of $129,800,502.

Hunting in Texas is also of significant economic importance. A Parks and Wildlife Department study in 1975 indicated that more than $74 million was spent by Texas hunters for firearms and hunting equipment. An earlier study noted that landowners were receiving approximately $100 million for annual hunting leases.

In the fiscal year 1977-78, some 447,560 Texans bought combination hunting and fishing licenses, 398,614 bought hunting licenses, and 912,576 bought fishing licenses.

With increased leisure time, more people than ever are turning to the woods and waters for recreation. Demands are rising for outdoor recreational facilities and for access to fishing and hunting sites. The wildlife of Texas is becoming increasingly important. Fishery and wildlife management, as a facet of natural resource conservation, presents a challenge to today's scientists and citizens.

Rangeland Resources of Texas

Rangeland is defined by the Society for Range Management as all land on which the native vegetation (climax* or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing. Included are lands revegetated naturally or artificially to provide a forage cover that is managed as native rangeland. Much of this land is not cultivated because of unsuitable climate, soil, or topography. Rangeland includes natural grasslands, savannahs, most deserts, tundra, alpine communities, coastal marshes, and wet meadows.

IMPORTANCE OF RANGELAND

Of the 168 million acres of land in Texas, approximately 100 million acres are rangelands. These lands support about 8 million cattle, 1.9 million sheep, 1.7 million goats, more than 3 million head of deer, and a large number of horses. The products of rangelands supply much of the meat, clothing, and recreational sport of the people of Texas. The combined economic returns of the rangelands of Texas are second only to the oil industry.

Rangelands are important to agriculture and to industry of the state. The relationship between the grazing of livestock and farming, for example, is significant. Livestock animals use many farm products and by-products that would otherwise remain unused. Frequently they are fed farm products such as grain, fodder, cottonseed, and other by-products. The public demand for livestock has a profound effect upon the maintenance of crop prices.

Relationships exist between livestock production and such industries as packing and slaughter, wool and woolen mills, railroads, trucking, grocery stores, leather manufacturing, and oil. Direct relationships also exist between the livestock industry and loan corporations, banks, and insurance companies. The prosperity of many communities is largely dependent upon the livestock industry.

The rangelands of Texas are not only important because of their ability to support livestock but because of their contribution to watersheds. Because water is essential to every phase of Texas' livelihood, watersheds must be properly managed for maximum and efficient production of water. One of the more important functions of vegetation is the protection of watersheds through the stabilization of soil and the conservation of water.

HISTORY OF RANGELAND USE

Early explorers described much of Texas as open grassland. One French explorer predicted that the pine woodlands of Texas would be the western population boundary of the United States because he found nothing but a "sea of grass" beyond. In those days, wood was essential for fuel and building purposes and its presence largely determined the feasibility of settlement. Other explorers described Texas with such eulogies as "grass, belly high to a horse," "open grassland with an occasional tree or thicket or shrubs," "grass so high that we had to tie our horses together for fear of becoming lost from each other," and "grass up to our saddles."

There is no doubt that Texas was once a relative "sea of grass," and the abundance of forage had a great influence on the heritage and settlement of the state.

Unfortunately, early cattle raisers did not know certain basic principles essential to proper and sustained use of vegetation. Overuse prevailed, and range deterioration resulted. Deterioration was accompanied by an invasion of certain species of vegetation that are undesirable

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*Climax plants are the highest form of plant community a particular environment is capable of producing.

This rolling prairie site in Hood County is in excellent condition.

because they are often unpalatable, low in productivity, injurious to animals, poisonous, or poor stabilizers of soil and water.

The increase of undesirable plants has had a profound effect on the range resources of Texas. Grazing capacities have declined, and the cost of livestock production through feeding has increased. Some areas that were once considered the best grasslands of Texas have slowly become wastelands.

Infiltration of water into soils of land once protected by grass has been reduced, and excessive runoff is not uncommon. Springs, creeks, and other small tributaries have ceased to have regular flow and now serve largely as flood channels. Accelerated erosion has reduced the basic productivity of rangelands and has contaminated the quality of stream water. The large hydroelectric and flood control reservoirs are subject to extensive siltation brought about by excessive erosion of denuded rangelands.

Results of range deterioration within the past 100 years has not been all bad, however. According to wildlife biologists, the number of white-tailed deer has multiplied with the increase of certain invading brush species. Also, bobwhite quail and other birds are dependent upon the fruits of certain plants that are not important for livestock forage and for soil and water stabilization. These species of wildlife and perhaps others have benefited somewhat from range deterioration; and, because they have economic and recreational value, they are considered in the management of rangeland.

CLIMATE

Climate has a direct influence on the potential vegetation of an area, particularly as related to the kind of vegetation and its value for forage. Climatic factors most related to vegetation are precipitation, evaporation, humidity, temperature, and length of the growing season.

The geographical distribution of precipitation in Texas is influenced by the area's distance from the Gulf of Mexico and by topographic features influencing prevailing air currents. As shown in Figure 1, the average annual precipitation varies from approximately 56 inches in the eastern portion of Texas to eight inches in the western portion. In general, the amount of average annual

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precipitation is highly related to the vegetation potential; however, it is merely a part of the climatic complex and not the sole climatic factor.

The effectiveness of precipitation cannot be determined by averages alone. The intensity and distribution of rainfall is of great importance. Very light rains during periods of high temperatures are of little value to plants because the moisture is evaporated very rapidly. The precipitation of West Texas is particularly low, generally less than 15 inches per year. It is not uncommon for a large percentage of the year's average precipitation to occur during a brief rainy period. During intense rainfall, much is lost by runoff when the grass cover is lacking. The potential value of the precipitation to the vegetation is thereby lost.

Seasonal distribution of precipitation as related to other climatic factors such as length of growing season and temperature is important. Most of the rangelands of Texas are characterized by relatively dry winters with the greatest amount of rainfall occurring during the spring and fall. This type of distribution is favorable for a warm-season grassland type of vegetation. However, the comparatively wet and warm winters of East Texas are conducive to a forest type of vegetation. Erratic precipitation is not an exception in Texas. Therefore, average precipitation will fluctuate from year to year, causing yearly fluctuation in plant growth and consequent forage production.

Humidity is important in determining the effectiveness of precipitation for plant growth. Plants can more efficiently use soil moisture in areas of high atmospheric humidity than in areas of low humidity, resulting in greater plant growth. The average humidity is much higher in the eastern portion of Texas than in the western.

Evaporation also determines to a large degree the effectiveness of precipitation. The potential rate of evaporation is largely dependent upon temperature, latitude, longitude, and length of day. The ratio between precipitation and evaporation is expressed:

$$\frac{\text{precipitation in inches}}{\text{evaporation from a pan}} = \text{precipitation-evaporation ratio}$$

The ratio has been used by several ecologists as an index to plant water stress. Areas with a ratio below 0.20 are classified as deserts, those between 0.20 and 0.60 are true prairies, and those in excess of 1.00 are capable of supporting continuous forests.

Figure 1 illustrates the average annual evaporation rate for Texas. A comparison of Figures 1 and 3 reveals that the eastern portion of Texas has a precipitation-evaporation ratio of 1.00 and the area between the 100th meridian and East Texas varies between a ratio of 0.30 and 1.00. The area west of the 100th meridian varies between a ratio of 0.30 and 0.10 with the Big Bend and portions of South Texas having an especially low ratio. Roughly, the central and eastern parts of Texas, excluding the pine woodlands, are climatically adapted to tall grasses, and the western portion is adapted to short grasses and desert shrubs.

Average temperature and length of growing season are closely correlated with the latitude of an area and are influenced to some degree by elevation and by proximity to the Gulf of Mexico. In general, Texas is characterized by a long growing season that varies from approximately 320 days in the Rio Grande Valley and along the Gulf Coast to 190 days in the North Central and High Plains regions. The long growing season results in plant growth during both the summer and winter months, thus providing green forage yearlong.

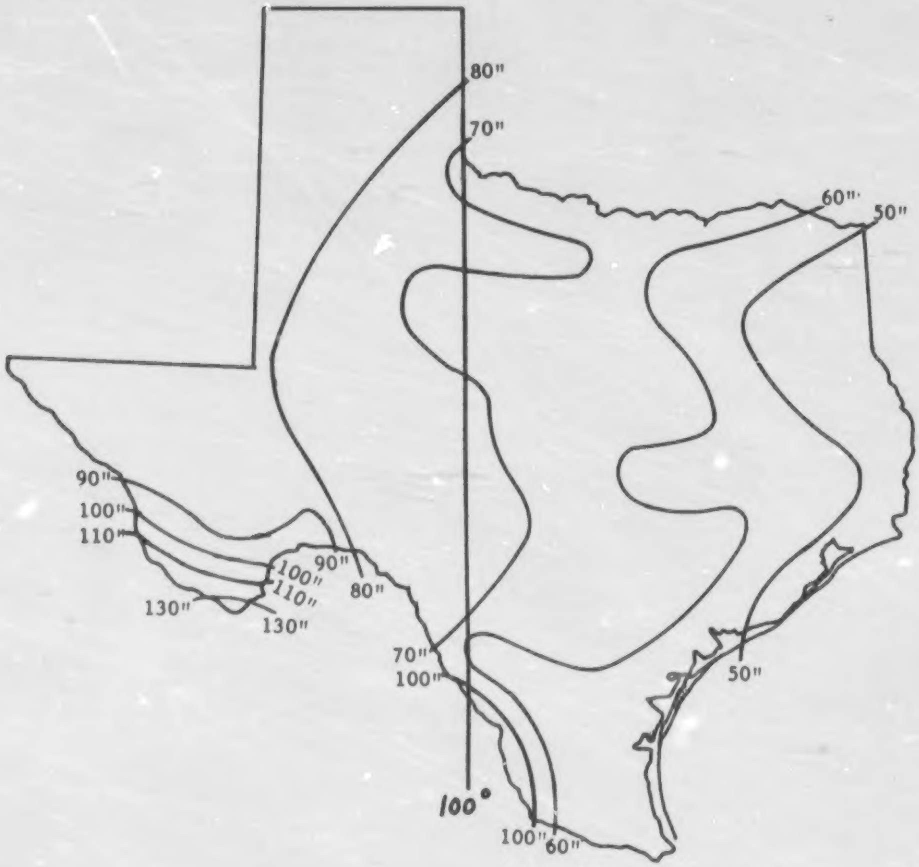

Figure 1. GEOGRAPHICAL DISTRIBUTION OF WATER EVAPORATION IN INCHES FROM EVAPORATION PANS

SOIL FORMATIONS

General soil characteristics related to geological formations have a great influence on the nature and kind of vegetation potential. The climate may be ideally suited for a particular kind of vegetation; however, it may not occur because of a deficient soil factor. The vegetation potential may thus be a result of the interrelationships of soil and climate.

Basically, Texas soils have been influenced by several geological formations of the Cenozoic, Mesozoic, and Paleozoic eras.* The actions of climate and biological complexes on the parent materials of these formations have created areas of similar soil characteristics. The similarities of soils as interrelated with the climate support similar kinds of vegetation.

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*See pages 1-26 for a discussion of Texas soils.

RANGE SITES

Variations in potential vegetation composition and forage production occur within each general vegetational area. These variations are caused by differences in either topography, soil depth, soil texture, slope, exposure, or erosion. Such differences represent a range site, which is defined as "an area of land having a distinct combination of edaphic, climatic, topographic, and natural biotic factors that is significantly different from adjacent areas."

To understand rangeland resources, it is essential to understand the factors influencing range sites. The plants that are adapted to a particular range site must be recognized because they are the plants best adapted to the environmental conditions of the site. With few exceptions, they are the most efficient users of the resources as well as the most desirable plants from a forage, soil, and water conservation point of view. The site, therefore, is an important key to what can be expected of a particular range or ranch. Failure to realize this can result in gross misuse and significantly lower forage and animal product production on these lands.

Range sites are designated by appropriate names, such as Claypan Prairie, that are descriptive of the easily recognized physical features within the general vegetation area.

MAJOR LAND RESOURCE AREAS

Pineywoods

The Pineywoods contain approximately 16 million acres of mixed pine and hardwood forest, pine being the fire subclimax.* Plants frequently found in these forests include blackseed needlegrass, Virginia wild rye, Canada wild rye, purpletop, broadleaf uniola, spike uniola, pine bluestem, switch cane, and brownseed paspalum.

Gulf Prairies and Marshes

Gulf Prairies and Marshes comprise approximately 9.5 million acres of Gulf Prairie and 500,000 acres of Gulf Marshes. Prairie sites' principal climax plants, plants representing the natural potential of an area, are tall bunchgrass. These include big bluestem, seacoast bluestem, Indiangrass, eastern gamagrass, switchgrass, and gulf cordgrass. Seashore saltgrass is frequent on moist saline sites.

The vegetation of the Gulf Marshes consists primarily of species of sedge, beakrush, bubrush, and rush; several species of cordgrass; and marsh millet.

Blackland Prairies

The Blackland Prairies contain approximately 12.5 million acres, with black clay-loam soil developed under prairie grass-forb vegetation. For the most part, this fertile area has been brought under cultivation, and only small acreages of meadowland remain in climax tall grass vegetation. In heavily grazed pastures, the tall bunchgrasses have been replaced by buffalograss, Texas grama, and other grasses of low productivity.

The climax grass vegetation includes little and big bluestem, Indiangrass, switchgrass, sideoats grama, hairy grama, tall dropseed, Texas wintergrass, and buffalograss. The prairie forb vegetation is composed largely of legumes and composites.

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*A fire subclimax develops when burning is introduced to a plant ecosystem to obtain desired results.

Cross Timbers and Prairies

The Cross Timbers and Prairies area comprises approximately 16.5 million acres of prairie and woodland sites. Sharp changes in the vegetational cover are associated with differences in soils and topography. In many areas, however, there is an intermingling of vegetational types.

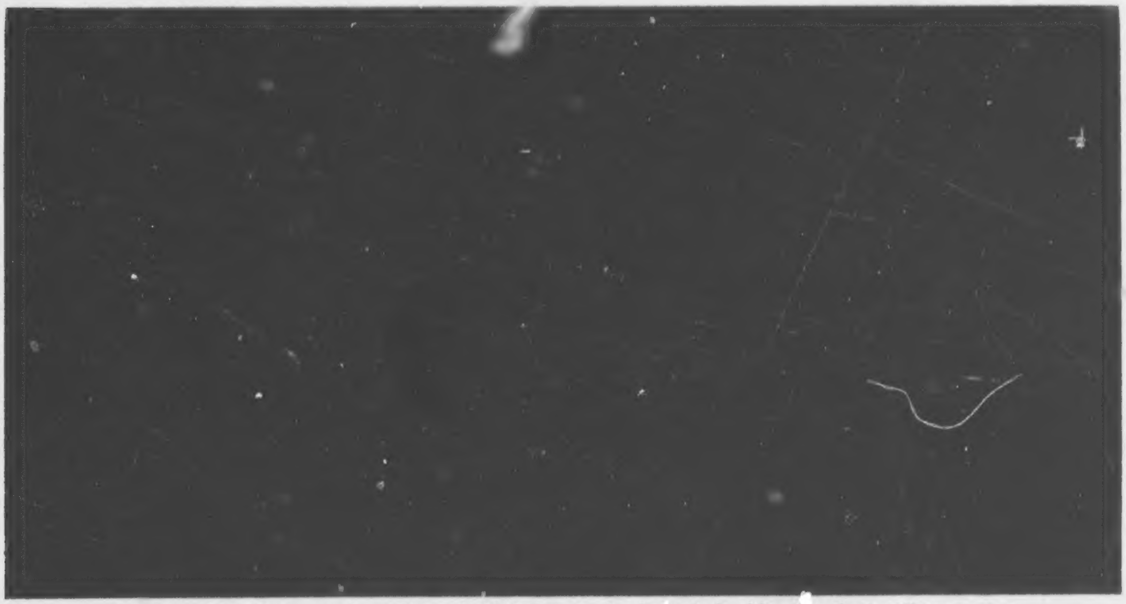
The climax prairie vegetation is composed primarily of big and little bluestem, Indiangrass, sideoats grama, blue grama, and buffalograss.

On the predominantly sandy soils of the Cross Timbers, the woodland vegetation is dominated by shinnery oak, post oak, and blackjack oak. The climax herbaceous vegetation is composed of big and little bluestem, sand lovegrass, Indiangrass, switchgrass, and many species of legumes and palatable forbs.

Rio Grande Plains

The Rio Grande Plains comprise approximately 20 million acres of mostly level terrain with diverse soil types and sites. The original vegetation was mainly perennial warm-season bunchgrasses, post oak, and live oak, with mesquite and other brush species frequently forming dense thickets on the ridges. Long-continued grazing has altered the vegetation to such a degree that now the region is known as the "brush country." Most of the desirable grasses have persisted under the protection of brush and cacti.

Characteristic grasses of the sandy loam soils are seacoast bluestem; species of bristlegrass; paspalum; windmill grass; and trichloris; silver bluestem; big sandbur; and tanglehead. The dominant grasses on the clay and clay loams are silver bluestem, Arizona cottontop, buffalograss, curlymesquite, and species of bristlegrass, pappusgrass, and grama. Low saline areas are characterized by gulf cordgrass, seashore saltgrass, alkali sacaton, and switchgrass. In the post oak and live oak savannahs, the grasses are mainly seacoast bluestem, Indiangrass, switchgrass, crinkleawn, and species of paspalum.



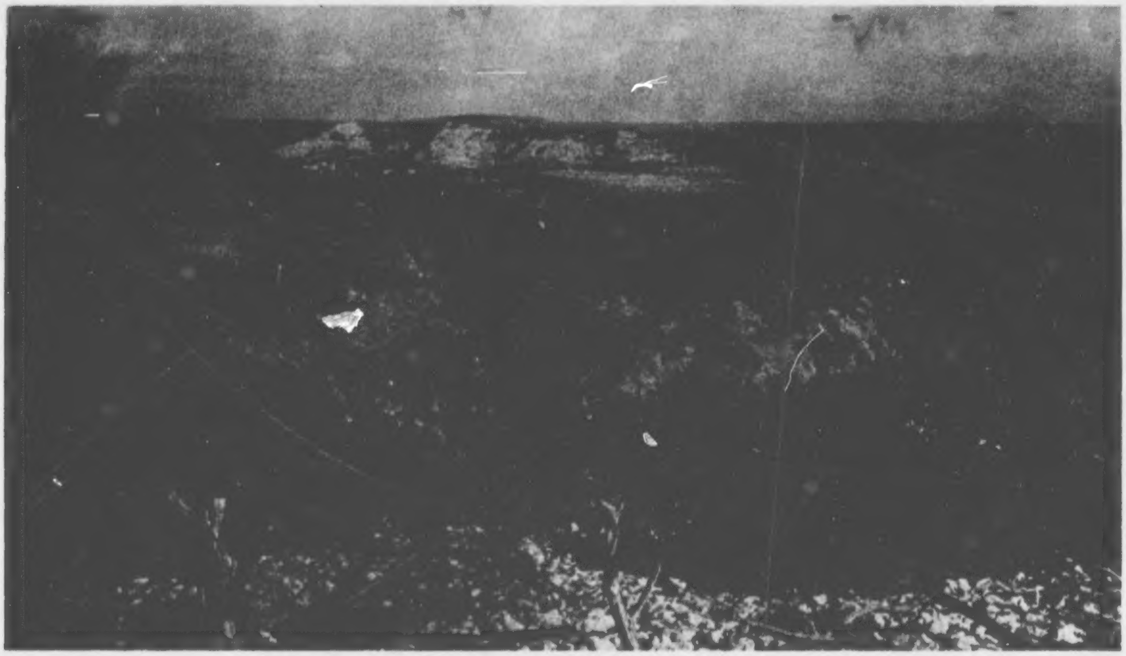
Loamy prairie site in good condition, DeWitt County, is characterized by abundant native grasses.

Edwards Plateau

This area, the Hill Country of West Central Texas, comprises some 22 million acres. The Edwards Plateau is a region of limestone outcrops and rocky but fertile soil. The western portion of the area is the semi-arid Stockton Plateau which has an annual rainfall of 18-20 inches or less.

The principal climax grasses of the area are cane bluestem, silver bluestem, little bluestem, sideoats, and hairy grama, Indiangrass, curlymesquite, buffalograss, and fall witchgrass.

Throughout the Edwards Plateau, live oak, shinnery oak, mesquite, and species of juniper dominate the woody vegetation.



Stony hill site contrasts with clay loam site in Edwards County.

Central Basin

The Central Basin is characterized by granite-laden soils. The area comprises some two million acres and is surrounded by the Edwards Plateau area. Mason, Llano, and Burnet counties are the heart of the Central Basin.

The principal climax grasses of the area are hooded windmill, sideoat grama, little bluestem, hairy grama, slim tridens, and curlymesquite. Woody plants characterizing climax range conditions include oak, catclaw, and persimmon. Many annual forbs also comprise a significant portion of the climax vegetation.

Rolling Plains

The Rolling Plains area has approximately 24 million acres of rolling-to-rough topography and mixed grassland vegetation. Soils range from coarse sands along outwash terraces adjacent to streams to tight or compact clays on red bed clays and shales. Rough, broken lands on steep slopes are found in the western portion.

The principal climax grasses are mixtures of big and little bluestem, sand bluestem, sideoats grama, Indiangrass, and switchgrass in the more sandy soils. Sideoats, blue grama, tobosa, and buffalograss are dominant on the tighter soils. Mesquite is a common invader on all soils. Shinnery oak and sand sagebrush are common on the deep sands.

High Plains

The High Plains contain approximately 20 million acres of level to slightly rolling plains with highly fertile clay and sand soils.

Blue grama and buffalograss are the principal vegetation on the clay and clay loam sites. Other important grasses are little bluestem, western wheatgrass, Indiangrass, and switchgrass on the sandy loam soils. Shinnery oak and sand sagebrush are conspicuous on sandy sites. Several species of dropseeds are abundant on course sands in the southern portion.

A rough breaks a rolling plains range site in Potter County.

Trans-Pecos: Mountains and Basins

The Trans-Pecos area of approximately 18 million acres includes most of the region west of the Pecos River. It is made up mainly of arid valleys, plateaus, and mountains. The mountains are 3,000 to 8,000 feet in elevation and support ponderosa pine and forest vegetation on a few of the higher slopes. The principal vegetation types are the creosote bush, tarbush, desert shrub, grama grassland, Yucca, Juniper savannahs, piñon pine, and oak forest. Species of saltbush are present on the saline soils.

The grass vegetation, especially on the higher mountain slopes, includes many southwestern and Rocky Mountain species not present elsewhere in Texas. On the desert flats, black grama, burrowgrass, and fluffgrass are frequently found. More productive sites have numerous grasses including grama, muhly, dropseed, and perennial threeawn. At the higher elevations, little bluestem, Texas bluestem, sideoats grama, blue grama, piñon ricegrass, and wolftail are found.

Rangeland management results in good condition on gravelly loam site, El Paso-Hudspeth Soil Conservation District.

MANAGING RANGELAND RESOURCES

The influence that humans have had on range resources is evident. People, through manipulations, can create conditions that are either desirable or undesirable for the rangeland environment. Effective managers of the rangeland practice scientific range management that encompasses a number of biological and physical disciplines. They understand what can be done to the land and how it will respond.

Range management has been defined by the Soil Conservation Service as the wise use and care of land on which the native vegetation (climax or natural potential plant community) is predominantly grasses, grasslike plants, forbs, or shrubs suitable for grazing or browsing.

A goal of scientific range management is maximum livestock production; however, also vital is perpetuation of the rangeland resources such as vegetation, soil, water, and various forms of wildlife. Grazing is but one use of most ranges, and the range scientist advocates the best use of the land as a whole.

PHYSIOLOGICAL ASPECTS OF RANGE PLANTS

The major resource of rangelands is the vegetation, which provides both forage for livestock and watershed protection. The function of range plants and plant communities as influenced by grazing must be understood before range management can be successfully directed. This is particularly true of the grass plants, because grasses are by volume the major forage species growing on Texas rangelands.

How plants produce food is a unique process. The plant leaf is made up of cells containing chlorophyll. Carbon dioxide from the air and water from the soil are converted to carbohydrates by the action of chlorophyll in the presence of sunlight, a process call photosynthesis. The carbohydrates are the bases for the plant food necessary for plant growth and energy. Photosynthesis is dependent upon several factors: physiological efficiency of the plant, amount of carbon dioxide in the air, area of leaf surface, intensity of light, water availability, temperature, and soil nutrients.

Any one of the above factors can limit the photosynthetic process. Management of the range can influence these factors, particularly the area of leaf surface and water availability. The area of leaf surface can be influenced by the intensity and frequency of grazing. Water availability is influenced by the response of the root system to grazing as well as by the amount of infiltration allowed by cover conditions created by grazing intensity. Since the roots are underground, they are difficult to study; yet, where water is vital, there is no part of the plant more important. The extent of the root system largely determines the amount of water available for plant functions, including photosynthesis. The amount of photosynthesis determines the amount of manufactured food for energy that can be used for plant growth and root renewal, which in turn enables the plant to absorb water from the soil.

The extent of a grass root system in comparison to the leaf system is in many respects remarkable. The botonist H.V. Dittmer has shown that a single winter rye plant can support 13 million distinct root members with a total surface of 2,554 square feet and a combined length of 387 miles.* An estimated 33 to 50 percent of a perennial grass' root systems die naturally each year. The rate of replacement is dependent on the amount of food available through photosynthesis. If the food is not available, the plant is weakened and the water supply for photosynthesis is correspondingly reduced.

A plant's health and productive ability also is significantly influenced by the degree of its use by livestock and other grazing animals. A healthy and productive grass can be maintained through an estimated 50 percent utilization of the current year's leaf weight. This degree of utilization will leave an adequate leaf surface for enough food synthesis for normal function of the plant. Continued use of the foliage at a rate greater than 50 percent results in a weakened and nonproductive plant. If the utilization is destructive or excessive over a long period of time, the plant will eventually die.

THE ROLE OF ECOLOGY IN RANGE MANAGEMENT

The original vegetation found by the early settlers has been termed climax. Since the climax is the highest form of plant community a particular environment is capable of producing, one environment may produce forest; whereas another will produce tall grasslands or desert shrub, depending upon the nature of climatic and soil factors.

As vegetation develops, a given site will be occupied by different plant communities of progressively higher life forms. In a process termed plant succession, the climax stage results from a series of successive waves of plant populations. Plant succession is a natural phenomenon that is of great importance to range resources.

The fact that one plant community can replace another is possible because of several natural factors. First, plants can migrate from one area to another. Migration of the seed (assisted by various agents) does not necessarily mean that the seed will germinate or that the plant will become established. Conditions have to be favorable for germination and for establishment. Germination and establishment are termed ecesis. After ecesis, the development of families and colonies of plants is termed aggregation. Again, aggregation is dependent upon favorable conditions. For example, if a species is very palatable and the range is overgrazed, ecesis and aggregation will not occur.

Plant survival is dependent upon plant competition. Plants are very keen competitors for the necessities of their life such as space, water, light, and nutrients. Only the adapted competitors are capable of dominating. The climax species for specific areas are the best competitors. Therefore, they dominate if given an opportunity. However, if the climax species are weakened through continued overuse and mismanagement, they lose controlling advantage. Other less palatable species then occupy the area and, because of their low palatability, have a competitive advantage as long as the overuse of the dominant species continues. With continued overuse of the climax species, these undesirable species may eventually dominate the area.

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*H.J. Dittmer, "A Quantitative Study of the Roots and Root Hairs of a Winter Rye Plant (Secale cerale)," *American Journal of Botany*, Vol. XXIV, No. 7 (1937), pages 417-420.

With proper management of the land, soil erosion is at a minimum, horizontal development has progressed as far as possible, organic deposition is at a maximum, as is physical structure and precipitation infiltration, while runoff is at a mimimum. A biological balance between plants and macro- and micro-organisms is attained. Destructive grazing upsets this equilibrium and results in changes in the plant and animal populations, excessive water runoff, and excessive soil erosion.

RANGE CONDITION CLASSIFICATION

Because climax vegetation represents the natural potential of an area in respect to plants and soil and water perpetuation, it serves as a basis for management. As a result, a range condition classification system has been developed in which present or existing vegetation can be classified according to its deviation from climax. Four range condition classes have been recognized: poor, fair, good, and excellent. Examples of these various range conditions are illustrated in Figure 2.

The species composition of a poor range condition contains from 0 to 25 percent climax species, fair contains from 25 to 50 percent, good from 50 to 75 percent, and excellent from 75 to 100 percent to climax. The efficiency of precipitation use is closely correlated to range condition. Infiltration increases with an improvement in range condition while surface runoff and evaporation decrease. Soil stability is also closely correlated with range condition. In addition, forage production and consequent grazing capacity are directly related to the class of range condition.

RANGE IMPROVEMENT PRACTICES

If applied annually, proper grazing use will either maintain or improve the range condition. The key to proper grazing use is to balance the number of animals, both livestock and wildlife, with the amount of forage so as not to exceed 50 percent utilization of the climax plants.

To maintain good and excellent range conditions and to improve poor and fair conditions, deferred grazing and/or planned grazing systems are essential. The climax species are limited on poor condition ranges; and continuous or yearlong grazing, often regardless of stocking rate, prevents the ecesis and aggregation necessary for plant succession and range condition improvement. Deferment during part or all of the growing season is favorable to plant succession. However, proper grazing techniques also promote upward plant successional trends.

Brush and noxious and poisonous plants often result as range deterioration occurs. About 50 million acres of rangeland in Texas are now occupied by undersirable plants. Reduction of the undesirable brush to reduce its competition with desirable forage species is necessary for plant succession. The brush should be controlled in such a manner as to create favorable habitats for wildlife and forage for livestock.

Poisoning of livestock by plants is more commonly the result of conditions, of kinds of animals, or of management than the actual presence of excessive numbers of the poisonous plants. In many cases, the poisoning of livestock can be prevented through proper management such as deferred grazing, proper stocking, noxious plant control, and grazing with different kinds of livestock.

Approximately 10 million acres of Texas rangelands have deteriorated to a point that improvement through natural plant succession is too slow to be practical. Range seeding, the process of establishing vegetation by the mechanical dissemination of seed, has been used with some success to return many areas to forage production.

Cross fencing, livestock water development, and proper grazing techniques are the most needed practices on many rangelands. These practices readily promote plant succession, increase forage production, and provide sustained economic returns.

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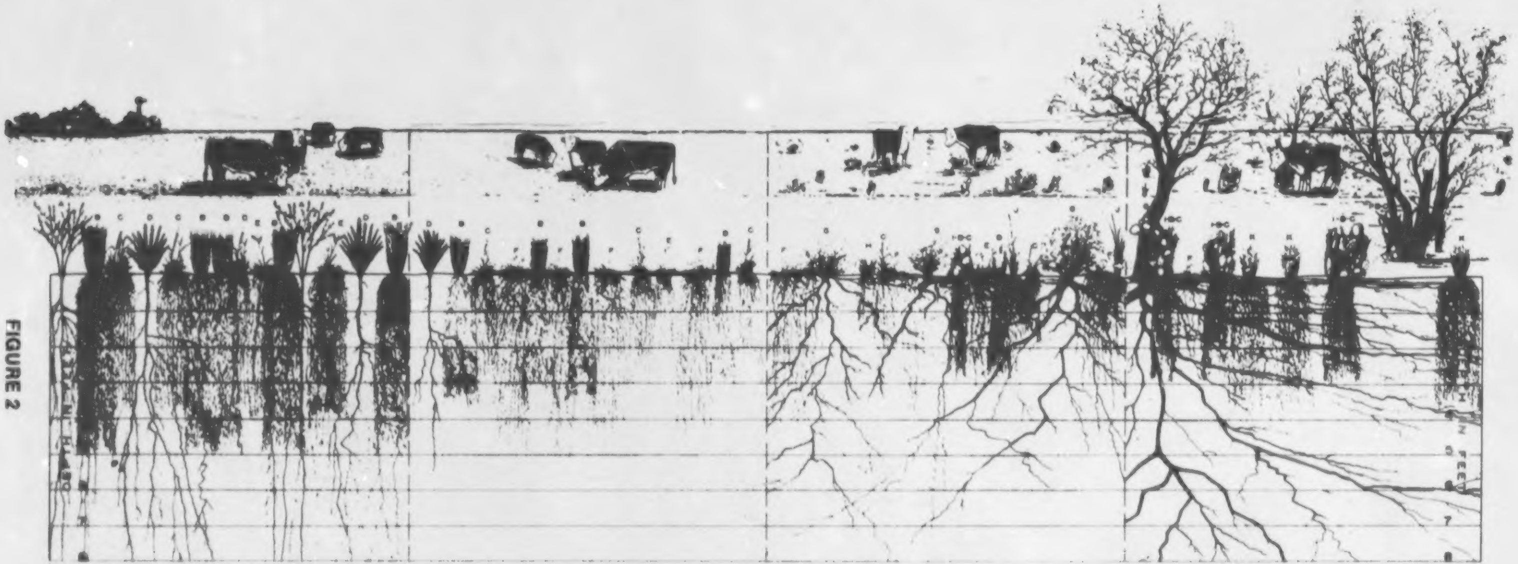
FIGURE 2

FOUR CLASSES OF RANGE CONDITION



EXCELLENT CONDITION

Little bluestem, sideoats, gramma, and forbs are most prominent plants. Roots penetrate deeply.

GOOD CONDITION

Buffalograss has invaded and is about as prominent as little bluestem and sideoats grama. Forbs are scarce, root systems are shorter.

FAIR CONDITION

Short grasses dominate, mesquite and other woody vegetation have invaded. Forbs have been killed and grass roots have shortened.

POOR CONDITION

Woody vegetation, threeawn, and inferior weedy vegetation have replaced the better forage plants.

LEGEND

A Wild-Alfalfa
B Little Bluestem
C Sideoats Grama
D Dotted Gayfeather
E Hairy Grama
F Buffalograss
G Mesquite
H Silver Bluestem
I Cactus
J Texas Wintergrass
K Treeawn

Mineral Resources of Texas

Texas leads the nation in total value of minerals produced, ranking first every year since 1934. As shown in Figure 1, Texas mineral production value exceeded $7.2 billion in 1972, over $1.5 billion more than the second ranked state. In 1977, Texas mineral production value was almost $20 billion, representing an increase since 1972 of 231 percent, due chiefly to the sharply rising unit values of mineral fuels (Table 1). Of the state's 254 counties, 211 produced some minerals in the mid 70s.

TEXAS MINERAL PRODUCTION

Mineral production in the state encompasses three basic categories of mineral commodities: mineral fuels, nonmetallics, and metallics. Mineral fuels include natural gas, petroleum, natural gas liquids, lignite, and a few other minor minerals. Nonmetallic minerals include at least 15 distinct commodities in Texas, principally cement, stone, salt, sand and gravel, lime, and gypsum. In 1977, iron, magnesium, sodium, and uranium were the principal metals produced from ores mined in Texas. Significant quantities of metals were recovered at smelters, refineries, and reduction plants; secondary metal recovery plants played an important role in recycling metal materials.

The relative importance of the three mineral categories to state mineral production value is shown in Figure 2. Mineral fuels account for the vast majority of Texas' mineral value. Nonmetallic minerals are next in importance with metallic minerals playing a relatively minor role. Tables 1 and 2 illustrate the market variety of Texas mineral production. Although oil and gas are the dominant reasons Texas leads the nation in mineral production, the state is truly unique in the magnitude and diversity of its mineral base. Texas is among the top five states in the production of 20 commodities, four of these related to the oil and gas industry (Table 2). Whereas emphasis on the oil and gas industry and its impact on the state's economy is well-placed, the full, diverse nature of Texas' mineral production should not be overlooked.

Mineral Fuels

Over 95 percent of the state's mineral production value comes from mineral fuels, principally petroleum, natural gas, and natural gas liquids. Petroleum accounted for almost 51 percent of the state's mineral production value in 1977 (Figure 3); natural gas, 32 percent, and natural gas liquids, 11 percent, also comprise significant portions of the state's mineral wealth. All other mineral fuels total less than 1 percent, though significant quantities of the other commodities are produced. For example, Texas leads the nation in production of native asphalt and crude helium. Lignite production in 1977 increased to 15 million tons, more than six times the level of production in 1972. Lignite is used in Texas to fuel steam electric power plants. Continued growth of lignite mining for Texas power generation is assured over the next decades.

Nonmetallic Mineral Commodities

Production value of nonmetallics in 1977 was $886 million, an increase of 65 percent over 1972 levels. However, the relative percentage of the state's total mineral production value declined from 6.2 to 2.14 percent in 1977. Many nonmetallic commodities experienced declines in output over the three-year period; nevertheless, most commodities increased in total value due to rises in unit value (Table 1). Though not as spectacular in terms of national and international rela-

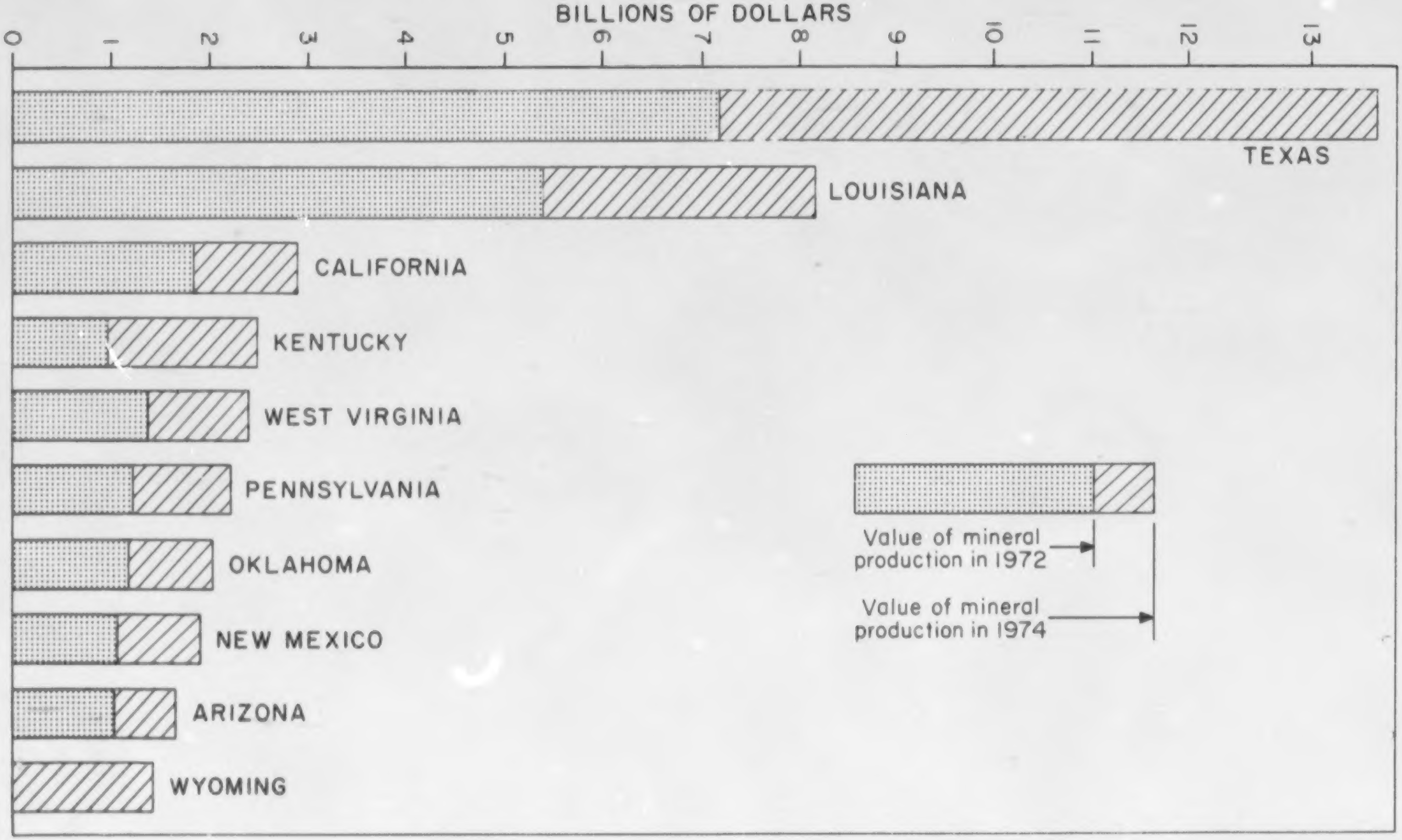


Figure 1. MINERAL PRODUCTION VALUE OF TOP 10 STATES, 1972

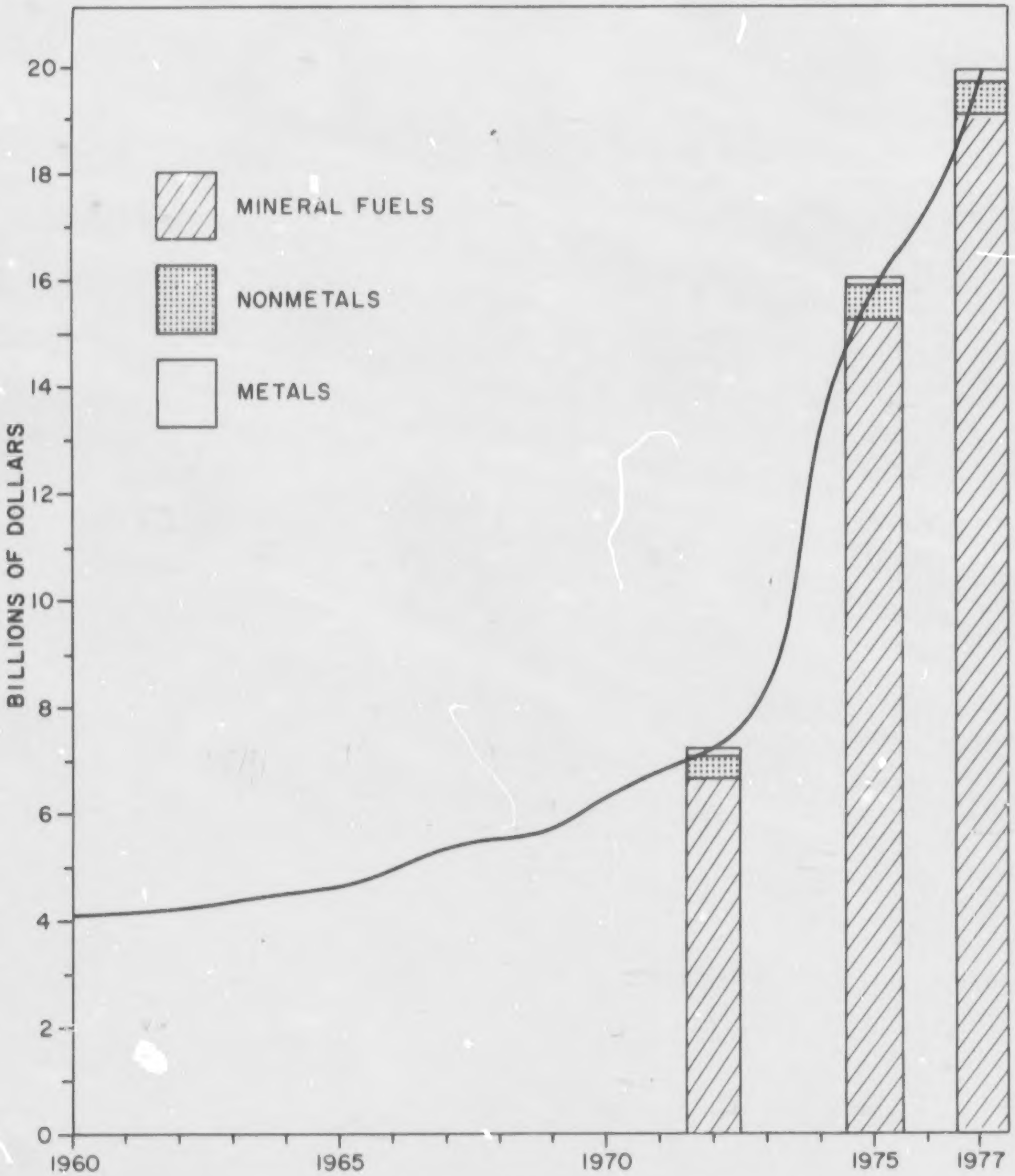


Figure 2. TEXAS MINERAL PRODUCTION VALUE BY YEAR WITH PROPORTIONS FOR MINERAL FUELS, NONMETAL COMMODITIES, AND METAL COMMODITIES FOR 1972 AND 1975

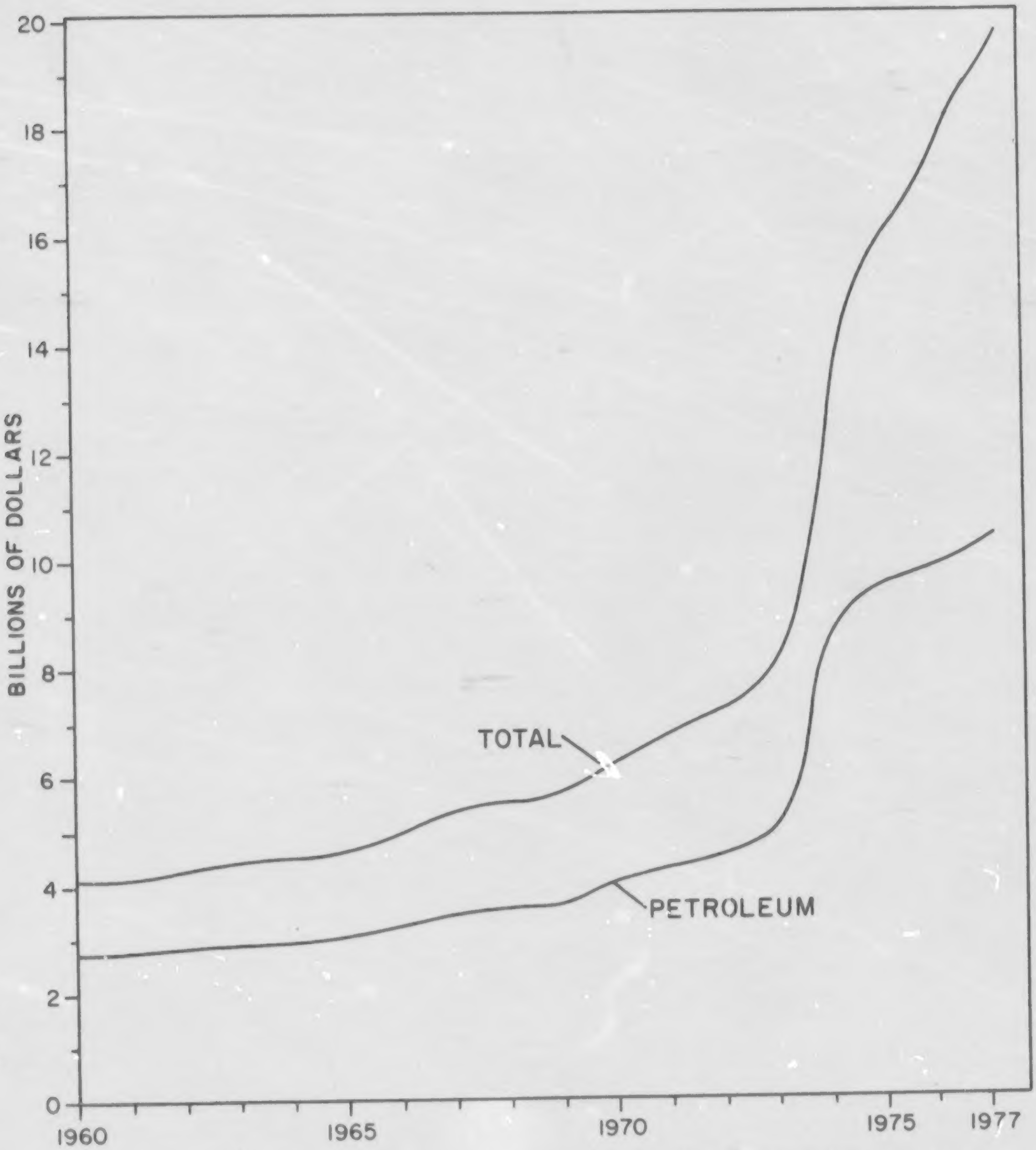


Figure 3. TOTAL TEXAS MINERAL PRODUCTION VALUE BY YEAR WITH PETROLEUM VALUE ALSO SHOWN

Table 1—MINERAL PRODUCTION IN TEXAS

Mineral			1972			1975p	
		Quantity	Total Value (thousands)	Average Unit Value	Quantity	Total Value (thousands)	Average Unit Value
Cement:							
portland	thousand short tons	7,813	$ 171,642	$21.97	7,285	$ 203,324	$27.91
masonry	thousand short tons	217	5,812	26.98	170	5,628	33.11
Clays	thousand short tons	5,175	11,554	2.23	4,322	12,896	2.98
Coal (lignite)	thousand short tons	4,045	w	w	11,400	w	w
Gem stones		NA	163	NA	NA	160	NA
Gypsum	thousand short tons	1,542	5,284	3.43	1,080	4,570	4.23
Helium (crude)	million cubic feet	1,026	12,312	12,00[2]	w	w	w
Lime	thousand short tons	1,631	22,181	13.60	1,694	36,590	21.60
Natural Gas	million cubic feet	8,657,840	1,419,886	0.16[2]	7,533,680	3,699,037	0.49[2]
Natural Gas Liquids:							
Natural gasoline and cycle products	thousand 42-gallon barrels	92,437	294,163	3.18	80,655	647,010	8.02
LP gases	thousand 42-gallon barrels	226,624	428,319	1.89	211,266	1,277,740	6.05
Perlite	short tons	2,391	24	10.04	—	—	—
Petroleum (crude)	thousand 42-gallon barrels	1,301,685	4,536,077	3.48	1,222,530	9,584,635	7.84
Salt	thousand short tons	9,744	36,544	3.75	10.886	55,247	5.08
Sand and gravel	thousand short tons	35,151	56,328	1.60	40,768	61,152	1.50
Stone (crushed only)	thousand short tons	49,314	66,573	1.35	59,161	107,041	1.81
Sulfur (Frasch)	thousand long tons	3,847	w	w	w	w	w
Talc and soapstone	short tons	221,022	1,262	5.71	150,000	1,400	9.33
Value of items that cannot be disclosed:							
Native asphalt, fluorspar, graphite, iron ore, magnesium chloride (for metal), magnesium compounds (except for metal), mercury (1972), pumice (1972), sodium sulfate, stone (dimension), uranium (recoverable content U_3O_8), and values indicated by the symbol W		xx	143,427	xx	xx	324,139	xx
TOTAL		xx	7,211,551	xx	xx	16,020,569	xx

p	Preliminary
xx	Not applicable
NA	Not available

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[1] Production as measured by mine shipments, sales, or marketable production (including consumption by producers)

[2] Standard unit of measure is 1000 cubic feet

[W] Withheld to avoid disclosing individual company confidential data; included with "value of items that cannot be disclosed" tions as oil and gas, nonmetallics play a vital part in the state's economy, particularly in the construction industry. Cement, sand and gravel, gypsum, lime, and crushed stone are consumed directly in residential, commercial, and highway construction. Salt and sulphur are two major nonmetallics produced in Texas and consumed principally in the chemical industry. Salt is used for soda ash and caustic soda; sulphur for sulfuric acid and manufacture of fertilizer. In addition, nonmetallic minerals display a wide range of utilization (Table 3).

Mineral Commodities

Production of metallics in Texas is not a major mineral industry; however, numerous secondary metal recovery plants (21 in 1975) and smelters, refineries, and reduction plants (18 in 1975) add greatly to the variety of metal industries contributing to the state's overall economy. Texas is currently ranked fifth in the nation in uranium output. The projected expansion of nuclear-based power generation in the United States suggests that uranium mining and milling will continue to grow. Iron ore production has increased 20 percent over 1976; the ore is used principally in the manufacture of iron and steel. In 1977 smelters, refineries, and reduction plants produced the following products: aluminum, antomony, cadmium, copper, iron, lead, magnesium, sodium, tin, tungsten, and zinc. Of these, iron, magnesium, and sodium are native metals. Secondary metal recovery plants treated steel, aluminum, lead, zinc, and tinned and other metal scrap to produce a variety of metal alloys, ingots, bars, heavy equipment, and other metal products.

TEXAS MINERAL ECONOMY

The economic impact produced by Texas' mineral resources is significant. Basically, mineral production creates jobs (1) at the site where minerals are produced, (2) in transit from production locality to processing facilities, (3) at the reduction plant, refinery, or other processing site, and (4) in distribution and sale of finished products. From producer to consumer, thousands of jobs are created and millions of dollars are spent in the form of salaries, taxes, licenses, fees, and royalties. The state uses the mineral-based revenues as part of its general income to provide services to every Texas citizen.

In the 1976-1977 fiscal year, taxes on oil and natural gas production added over $900 million to the state treasury—over 11 percent of the state revenues for that year. More intangible are the many millions of dollars from ad valorem taxes on the property owned by these and other mineral producers.

The petroleum industry accounted for approximately 250,000 jobs and paid almost $2.7 billion in wages in 1974. Other mining industries employed about 7,000 persons during the same period. Not included in these totals are the many workers employed in businesses and industries that exist to service, supply, and support the major mineral industry complexes.

DISTRIBUTION OF MINERAL RESOURCES

Texas is mineral-rich, but mineral deposits do not occur everywhere in the state. Some commodities, such as oil, natural gas, and sand and gravel, are produced in many counties. Most commodities, however, are produced in but a few localities in the state. Figure 4 illustrates the statewide distribution of several important mineral resources, exclusive of oil and gas.

Some minerals have a high unit value. They are rare or highly priced commodities that are produced wherever they occur regardless of other factors. Oil, natural gas, uranium, salt, and lignite are examples of high-unit-value commodities. Other minerals have a low unit value, but are still valuable because they occur near areas where there is a large demand. Construction materials (sand and gravel, stone, some clays, and cement) are examples of high-place-value (low-unit-value)

Table 2. RANK OF TEXAS MINERAL PRODUCTION RELATIVE TO OTHER STATES, 1977

Commodity	Rank	Commodity	Rank
Asphalt (native)	1	Salt	2
Graphite	1	Gypsum	3
Magnesium chloride	1	Talc, soapstone	4
Natural gas	1	[1]Cement	5 (portland)
Natural gas liquids	1		2 (masonry)
Petroleum, crude	1	Uranium	5
Sulfur (Frasch)	1	Lime	5
Sulfur (recovered)	1	Stone	3
Clays	3	Sand and Gravel	3
Sodium Sulfate	2	[2]Mercury	0
Helium	3	[3]Coal (lignite)	11

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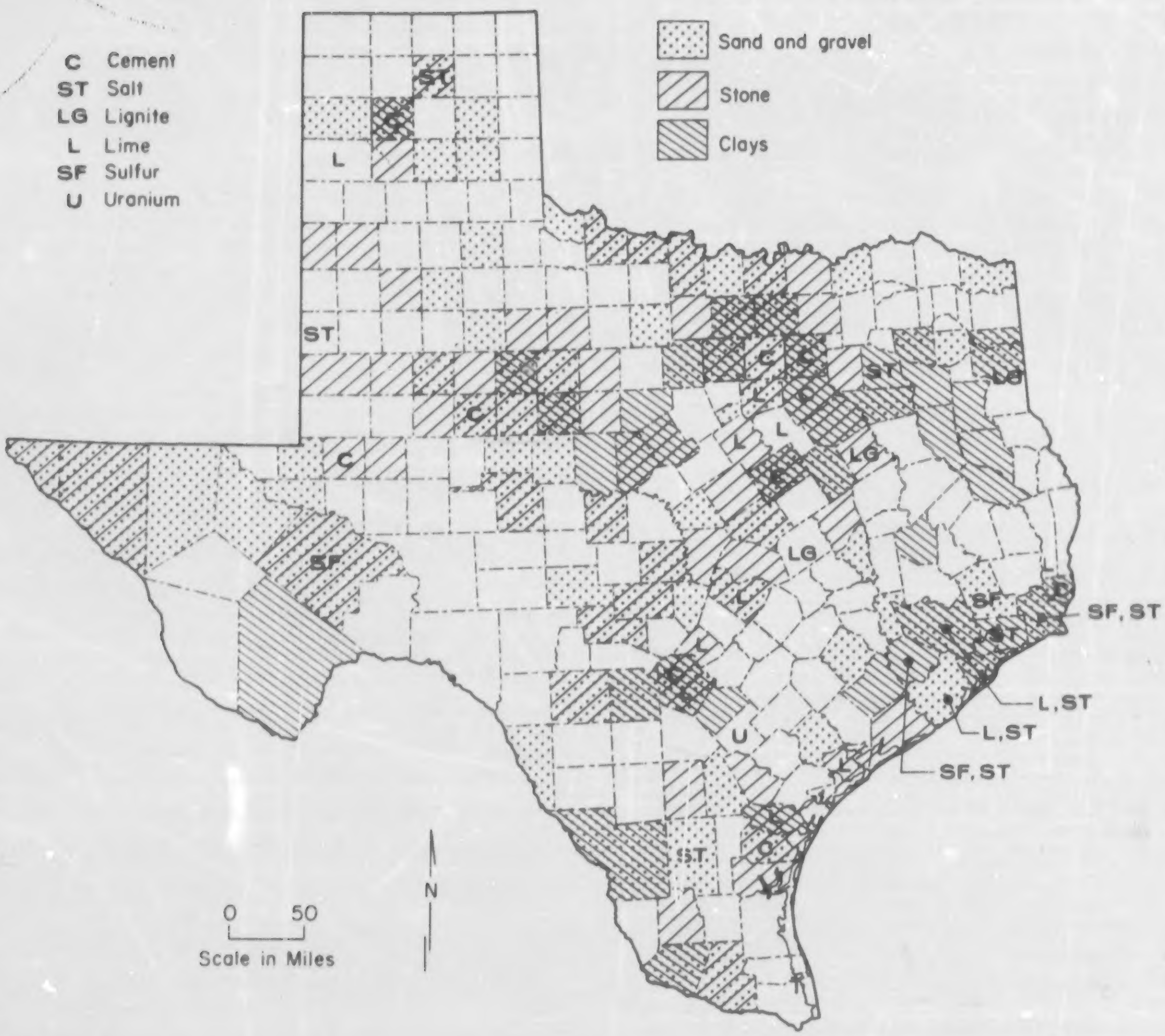
[1] Texas ranked first in the nation in cement production in 1975.

[2] According to the preliminary production figures from U.S. Bureau of Mines, mercury was not produced in 1975.

[3] Texas lignite production exceeded 11.4 million tons in 1974—ranking Texas about tenth among coal-producing states.


C Cement
ST Salt
LG Lignite
L Lime
SF Sulfur
U Uranium
Sand and gravel
Stone
Clays
ST
L
ST
C
C
C
C
SF
L
L
LG
LG
LG
L
C
U
ST
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SF, ST
ST
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L, ST
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0 50
Scale in Miles
N

Figure 4. NONMETALLIC MINERAL COMMODITIES PRODUCTION SHOWN BY COUNTY

commodities; these items are consumed near major urban-industrial centers in Texas. Commodities having high unit values are generally sold in many places, wherever consumer demand is high. High-place-value commodities can only be sold to nearby consumers, and deposits of these minerals located far from potential markets have no real value.

MAJOR MINERAL INDUSTRIES OF TEXAS

Lignite

In addition to its abundant resources of oil and gas, Texas has many billions of tons of lignite. Lignite is a brownish-black coal containing about 30 percent moisture and yielding about 7,500 Btu's* of heat per pound. One ton of lignite contains the equivalent heating value of approximately three barrels of oil or 15,000 cubic feet of natural gas.

Texas contains over 100 billion tons of lignite within 5,000 feet of the land surface and over 10 billion tons within 200 feet of the surface, the maximum depth for present surface-mining techniques. These large energy resources are contained in three groups of rocks that are exposed in long parallel bands on the Texas Coastal Plain (Figure 5).

Before petroleum and natural gas became the prime sources of the state's energy, lignite was mined extensively in shallow underground mines. Most of these mines closed soon after World War I, and the lignite industry remained small until very recently. Since 1971, lignite production has risen from approximately two million tons per year to over 15 million tons in 1977.

Lignite is mined as a fuel to generate electricity by producing steam to drive turbine generators. Lignite-fueled steam-electric power plants require from about three to as much as eight million tons of lignite every year depending on plant size. Several lignite-fueled power plants are already providing electricity to Texas citizens, and several more plants and expansions of existing plants will be completed in the near future. It is estimated that as much as 14,000 megawatts of electrical generating capacity, requiring as much as 70 million tons of lignite per year, will be available in Texas by 1985. Lignite is presently mined in large surface mines near the electricity generators. Mine-mouth operations are constructed because it is cheaper to transfer energy as electricity over transmission lines than to have the lignite transported by railroad or truck to major urban centers. Lignite is a high-unit-value commodity.

PROTECTION OF THE ENVIRONMENT—All of the active lignite mines (as well as the proposed mines) are large strip mines. Modern surface-mining techniques require large power shovels and draglines to remove (strip) the overburden on top of the lignite to expose the seam for production (Figure 6). Since each acre of land with an eight-foot-thick seam contains 14,000 tons of lignite, a mine supplying the more than five million tons per year required for a typical 1,000-mw power plant will disturb over 350 acres of land every year. These acres of mined land cannot remain unreclaimed for the Texas Legislature passed a law in 1975 requiring the reclamation of such mines.

Reclamation of mined lands at large lignite mines in the state involves reshaping the long rows of conical spoil piles or overburden which are created by the mining process. The reshaped and leveled land is reseeded and made ready for further reclamation procedures. Oxidation of sulfur and other elements associated with lignite occurs rapidly upon exposure of the coal seam. Therefore, surface and ground waters may readily pick up these oxidized compounds and produce acid water. Dangers from acid mine drainage are most acute in mines producing coals containing large amounts of sulfur. Texas lignite now in production is low in sulfur. However, even these, as well as future mines that may develop lignite with higher sulfur contents, are reclaimed to minimize the generation of acid waters and to restore the land surface to its original condition (or to another substantially beneficial use) as soon as possible after mining.

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*Btu's (British thermal unit) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

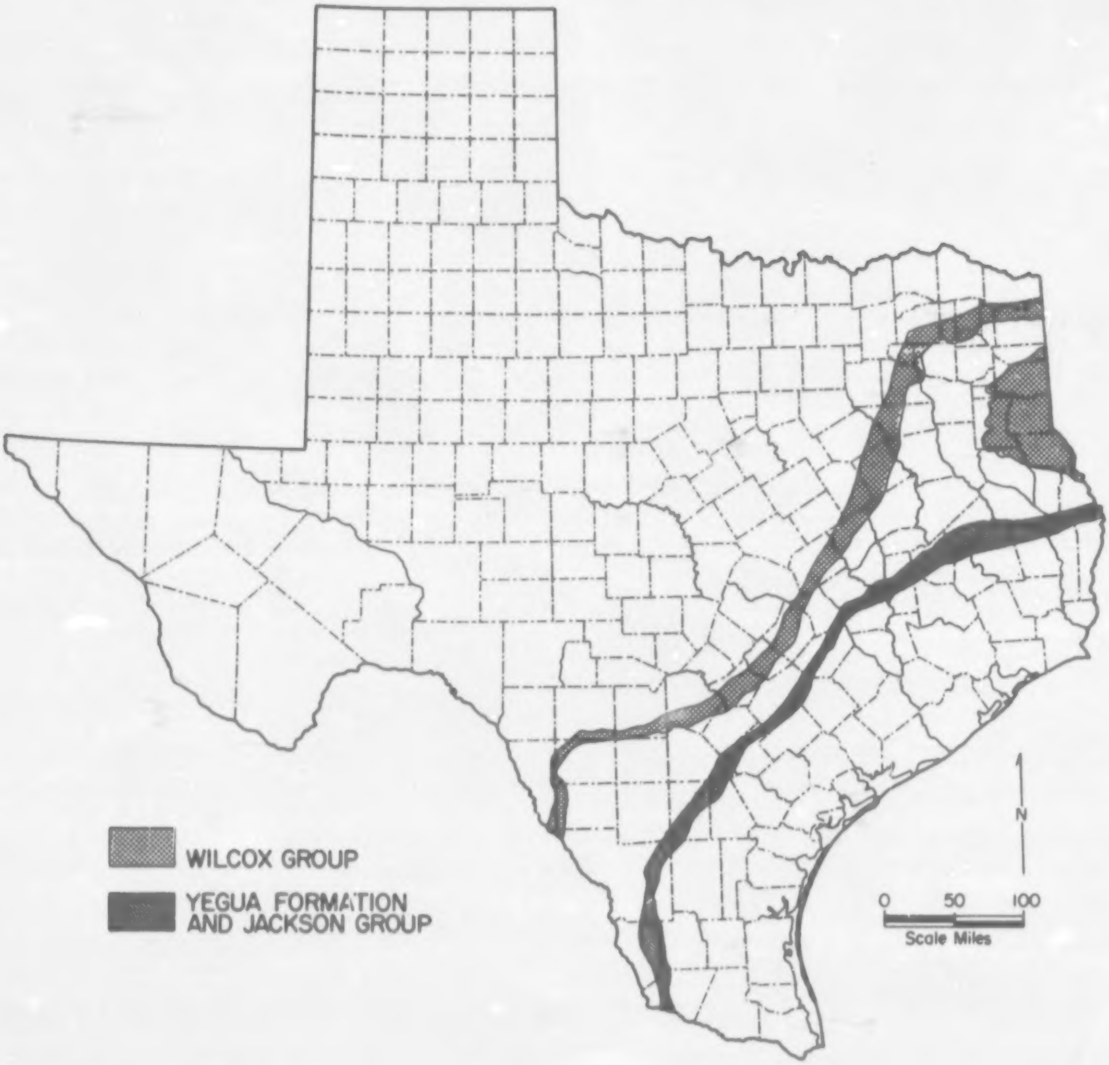
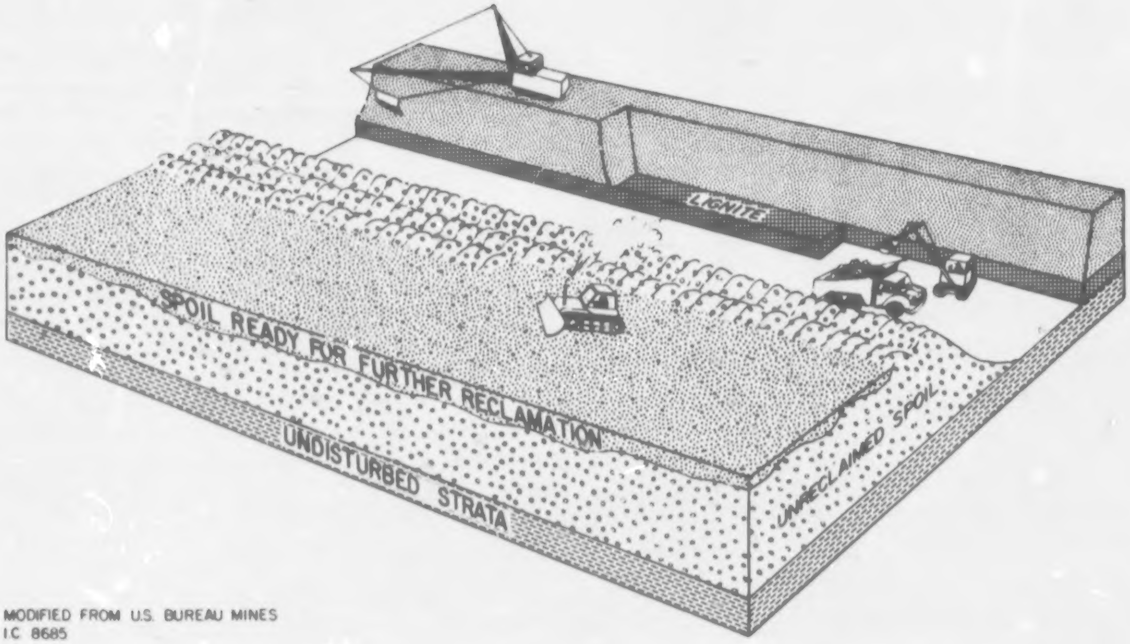

WILCOX GROUP
YEGUA FORMATION AND JACKSON GROUP
N
0 50 100
Scale Miles

Figure 5. DISTRIBUTION OF LIGNITE-BEARING STRATA (OUTCROP) IN TEXAS


LIGNITE
SPOIL READY FOR FURTHER RECLAMATION
UNDISTURBED STRATA
UNRECLAIMED SPOIL

MODIFIED FROM U.S. BUREAU MINES
I.C. 8685

Figure 6. TYPICAL LIGNITE STRIP MINE IN TEXAS

Environmental regulations also extend to the amount of certain pollutants (sulfur oxides, nitrous oxides, and particulates) permitted to be introduced into the air from coal-fired power-plant waste gases. Because of recent legislation requiring the reclamation of the lignite mines, the possibility of water and air pollution, as well as of land-surface disturbance, will be considered before a permit to mine the lignite resource is issued.

Limestone

Texas contains many trillions of tons of limestone. These vast limestone resources (Figure 7) are mined to support major cement, crushed stone, and lime industries. In 1977, Texas was the fifth leading producer of crushed limestone. Texas ranked second in portland cement production and fifth in masonary cement production and lime production. More than 150 quarries produce limestone for cement, lime, crushed and broken stone, and dimension stone.

STONE—Table 4 lists limestone uses, production, and value. Most limestone is produced for aggregate, principally used in the construction of roads, concrete structures, and so forth. Limestone produced for cement and lime are the next largest uses, followed by use as fluxstone and agricultural lime. In the iron and steel industry, limestone is commonly used as flux to promote the removal of impurities from the molten metal. Agricultural lime refers to the use of finely ground limestone to neutralize soil acidity and to enhance general soil condition by improving tilth, increasing nutrients, and encouraging development of organic matter. A wide variety of fine-grind products are used as fillers, extenders, and pigments in many materials. These products commonly have higher unit values reflecting the larger expense of grinding material to a small size. Crushed and broken limestone is a diverse mineral resource. Use of Texas limestone as a dimension stone includes rough stone (flagging, irregular-shaped blocks, and house stone veneer) and dressed stone (cut and sawed stone). Stone produced for building purposes is a high-value commodity. Three Texas quarries produced dimension stone in 1975.

Crushed or broken limestone is produced in quarries where massive exposures of the consolidated stone are blasted and trucked to crushers nearby. In the primary crushers, rocks up to several feet across are broken into about six-inch stone, and this stone is then further processed to produce a wide variety of aggregates. Generally, the aggregates required for the various construction industries have different size requirements, and the crushing and grading plant of each quarry is designed to produce the aggregates needed for its various consumers.

Smaller-size aggregates tend to be more expensive since they require more energy to produce. Another factor in stone value is the quality of the stone. High-calcium limestone (at least 97 percent $CaCO_3$) is not as common as other limestone, and users requiring high-purity limestone (for example, for lime or fluxstone) generally pay a higher unit price for the stone. Users of crushed and broken limestone, such as roadbase stone, commonly set physical standards that the crushed stone must meet; generally, the low-purity limestones are less likely to meet these physical standards.

CEMENT—Limestone is the major raw material in the production of cement.[*] More than 6.9 million tons of limestone produced in Texas in 1975 were used to manufacture cement. In 1977, Texas was the second leading producer of portland cement in the nation and fifth leading producer of masonry cement. Eighteen plants produce portland cement in Texas with 14 of these also producing masonry cement (a mixture of portland cement, pulverized limestone, and other additives for use as a mortar). Portland cement is used in ready-mix concrete, precast and prestressed concrete, concrete masonry, concrete brick, and concrete roofing tile. "Portland" is a generic term used to describe any cement that hardens in the presence of water and is made to standard specifications.

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[*] Other raw materials available for cement production in Texas include clay, sand, gypsum, iron-rich materials, bauxite, and fluorspar.

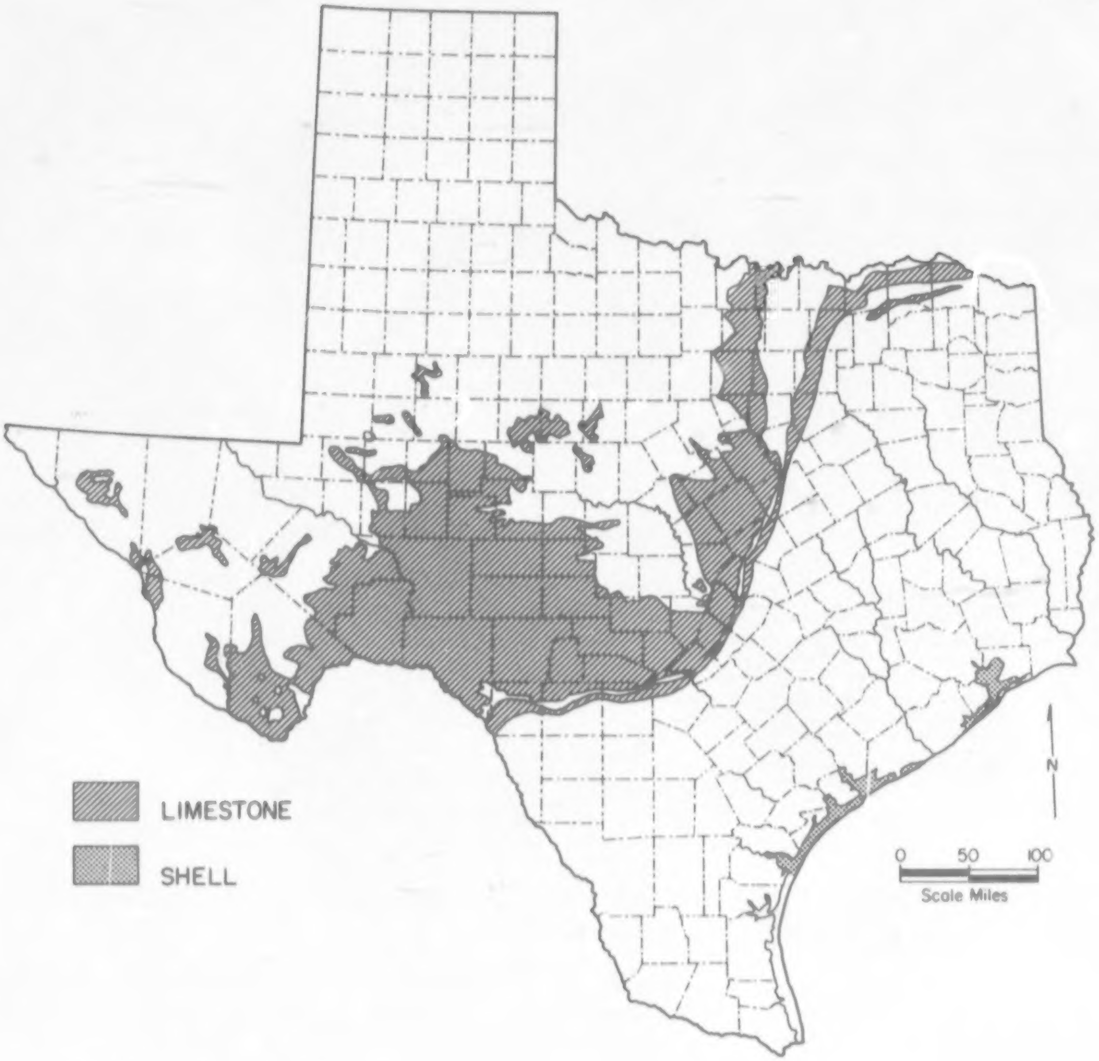
LIMESTONE
SHELL
N
0 50 100
Scale Miles

Figure 7. DISTRIBUTION OF LIMESTONE AND SHELL RESOURCES IN TEXAS

Table 3—USES OF PRINCIPAL NONMETALLICS PRODUCED IN TEXAS

Cement	Construction purposes (hydraulic, masonry, and pozzolan cement; special cements such as oil-well, white, plastic, hydroplastic, and waterproofing)
Sulfur	Sulfuric acid (mainly for fertilizer production), chemical industry, iron and steel, pulp, pigments, rayon, films, and explosives
Stone	Crushed: aggregate, railroad ballast, road material, riprap, cement, lime, fluxstone, soil conditioner, filler, mineral food, poultry, grit, alkalies, asphalt filler, paper, and glass
Salt	Chemical industry (sodium and chlorine for soda ash, sodium metal, chlorates, hydrocloric acid, and others); soap dyes, textiles, leather processing, meat packing, fish curing, water purification, ice and snow control, table use, and metal processing
Sand and Gravel	Constructional purposes (road material, aggregate, fill); industrial and specialty sands (abrasives, glass, chemical industry, refractories, metallurgical processes)
Lime	Chemical industry, flux material, soil conditioner
Clay	Ceramics, refractories, filler, coating, drilling mud, moulding clay, absorbent, cement, light-weight aggregate

Cement is manufactured from a mixture of about 80 percent limestone with the remainder being sand, clay, and other materials that provide aluminum, iron oxide, and silica in proper proportions. This mixture is then ground to about the particle size of flour and is heated at high temperature to cause the material to fuse, release carbon dioxide, and form the principal synthetic compounds called "clinker." To slow the rate at which cement hardens, gypsum is mixed with the "clinker," and this mixture is ground to a powder-size material known as finished portland cement.

Shipments of portland and masonry cement from 18 Texas plants in 1975 totalled more than $231 million of value. Gross revenue taxes for cement add several million dollars each year to the state treasury. Limestone production for cement manufacture is an important mineral industry in Texas; cement ranks next in mineral value to petroleum, natural gas, and natural gas liquids.

LIME—Limestone is principally calcium carbonate and is the only raw material used to produce lime (calcium oxide). Lime is produced by burning the limestone to drive off carbon dioxide, leaving calcium oxide behind. Lime produced in Texas is used for water purification; manufacture of magnesia, magnesium compounds, and other metal products; soil stabilization; manufacture of alkali compounds, paper, and pulp; and many other uses.

In 1977 almost two million tons of limestone were quarried, crushed, and heated to produce 1.59 million tons of lime. The lime was produced in 13 plants.

SHELL—Oyster shells dredged from Texas bays have been an important source of calcium carbonate for cement, lime, and a variety of aggregate uses along the highly industrialized Texas Gulf coast. In 1975, over 3.5 million tons of shell were produced with about half used to manufacture cement. Shell production has been steadily declining for several years due to shrinking reserves of legally available shell material. Strict regulations governing shell dredging in Texas bays are designed to protect living oyster reefs from excessive siltation. Texas coastal industries requiring calcium carbonate now import most limestone from Central Texas. It is likely that this trend of declining shell production will continue in the future.

PROTECTION OF THE ENVIRONMENT—Environmental concerns of limestone production center on the fact that limestone is hard and needs to be broken by explosives. Further preparation of the stone requires truck transportation to the crushers, which reduce the stone to marketable products. Dust, noise, and unpleasant aesthetic qualities of the limestone pit itself are created as part of the mining and preparation process. A number of these concerns are not easily ameliorated. For example, some dust can be controlled by frequent watering or oiling, but the dust derived from blasting is not generally controllable. Noise from blasting and truck traffic is unavoidable. Removal of limestone leaves a quarry that cannot be easily refilled as little waste material remains following stone extraction. To counteract the less pleasant qualities of stone production, blasting is often confined to a certain period (or periods) of each working day to restrict noise and vibration. Further, careful location of quarries and the use of landscaping can minimize the visual impact of the quarries. Dust problems are handled mainly by operating with enclosed conveyor systems or by utilizing preparation processes involving water.

Sulfur

Texas led the nation in the production of sulfur in 1977. Sulfur is one of the most valuable nonmetallic minerals produced in the state. Two basic methods are used to produce sulfur: recovery from sulfur-rich hydrocarbons and Frasch mining. Sulfur is produced principally along the coast and in West Texas (through both recovery and Frasch methods), as well as in East Texas and the Panhandle (through the recovery method).

Elemental or native sulfur occurs naturally in porous limestones associated with salt dome caprocks (Gulf coast) and anticlinal flexures in West Texas (Figure 8). Sulfur-reducing minerals, such as anhydrite, are reduced to produce sulfur. Associated hydrocarbons are believed to be another mechanism for producing elemental sulfur. Porous limestone is the host rock. Gypsum and anhydrite, which are commonly associated with salt deposits and are minerals deposited in an evaporite basin or strata formed in salt dome caprocks, are the source of the sulfur.

Frasch mining is employed to produce native sulfur from caprock and from bedded sulfur deposits. Seven Frasch operations are currently operating in Texas. The Frasch technique uses hot water (about 320°F) pumped under pressure into the sulfur-bearing horizon to melt the sulfur and return it to the surface with the compressed air. Figure 8 illustrates this mining technique. The sulfur-air slurry is then stored and allowed to cool and solidify. From 1,500 to 7,000 gallons of hot water and 500 to 900 cubic feet of air under 500-700 pounds per square inch pressure are required to produce one ton of sulfur. Sulfur recovery using the Frasch method is closely dependent on the porosity and permeability of the host strata and on the amount of sulfur present.

About 50 sulfur-recovery plants currently operate in Texas extracting sulfur from sour gas (sulfur-bearing natural gas), petroleum, and other smelter or industrial gases. Natural gas is the principal source of recovered sulfur in Texas; hydrogen sulfide is scrubbed from the gas stream by using organic chemicals. The hydrogen sulfide is burned in the presence of catalysts to produce sulfur and water or sulfur dioxide and water. Sulfur dioxide can be processed further to produce elemental sulfur. In 1976, sales of recovered sulfur were approximately 3,415,000 long tons, valued at near $200 million. Over $5.5 million were added to the state treasury in the 1973-74 fiscal year from taxes on sulfur production using both Frasch and recovery methods.

As stated previously, sulfur is a diverse nonmetallic resource. Over three-fourths of the sulfur is made into sulfuric acid, used principally to produce fertilizer. Sulfuric acid is also used in the chemical industry, as well as in a wide range of other uses. Nonacid use of sulfur is principally for paper pulp and manufacture of carbon disulfide.

PROTECTION OF THE ENVIRONMENT—Environmental damage resulting from sulfur production is not severe. Subsidence of the land-surface over strata from which sulfur has been removed can occur on a local scale. However, the use of special muds to maintain pressure and to fill subsurface voids helps minimize such damage. Sulfur-recovery operations can pose problems for local water supplies; however, regulations and enforcement of water quality standards protect Texas waters.

Salt

Salt is a major nonmetallic mineral produced in Texas. In 1977, 11 operations produced over 9.718 million tons of salt valued at over $42 million. Salt is produced from salt domes (Texas Coastal Plain) as well as from bedded salt deposits in West Texas (Figure 9). Salt production is generally by brine recovery, although direct underground mining occurs at two locations.

Millions of years ago general climatic conditions in parts of what is now Texas favored the deposition of salt. These evaporite basins also contain deposits of gypsum and anhydrite. The bedded salt is recovered in West Texas in the form of brines—either from solution mining or from direct recovery as natural brines. In the Texas Coastal Plain, salt domes have pushed up from a large salt bed into overlying strata in response to the pressure of the rock overburden. Salt from these domes is produced in the form of brines (solution mining) and by room-and-pillar mining.

Solution mining uses water to dissolve the salt and compressed air to lift or drive the heavy brine to the surface, where the salt may be recovered through evaporation or the brine may be prepared for direct use. Underground salt mining employs techniques common to other mining operations: construction of large rooms maintained by pillars of unremoved salt. The mined rock salt is then crushed for further handling and processing. Environmental concerns are limited to protection of surface waters and of vegetation from exposure to the highly saline brines.

Salt has a wide variety of uses (Table 3). Principal consumption of salt is in the chemical industry for manufacture of soda ash, sodium metal, chlorine, hydrochloric acid, and other chlorine and sodium compounds. Salt is also used as a preservative and seasoning, for soil stabilization along roads, for ice and snow control, for smelting and refining metals, and for table and household use.

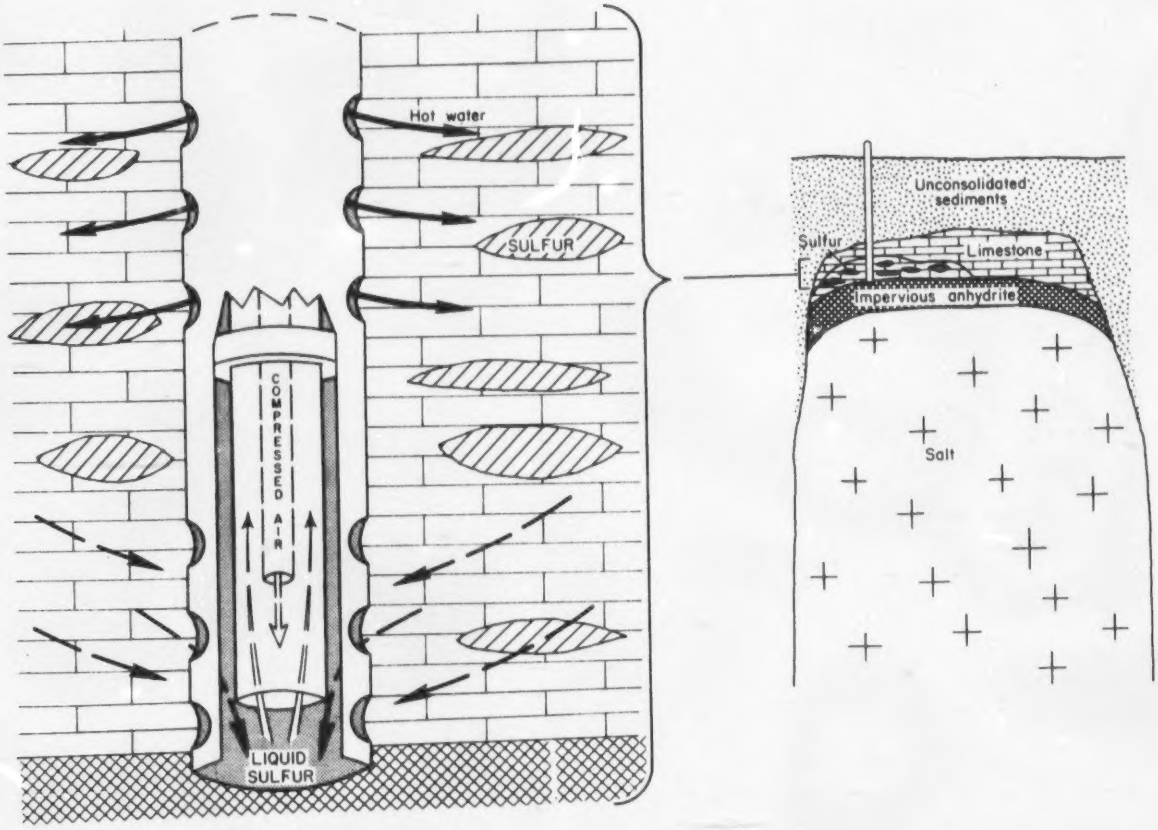
Hot water
SULFUR
COMPRESSED AIR
LIQUID SULFUR
Unconsolidated sediments
Sulfur
Limestone
Impervious anhydrite
Salt

Figure 8. HOW THE FRASCH SULFUR MINING PROCESS WORKS

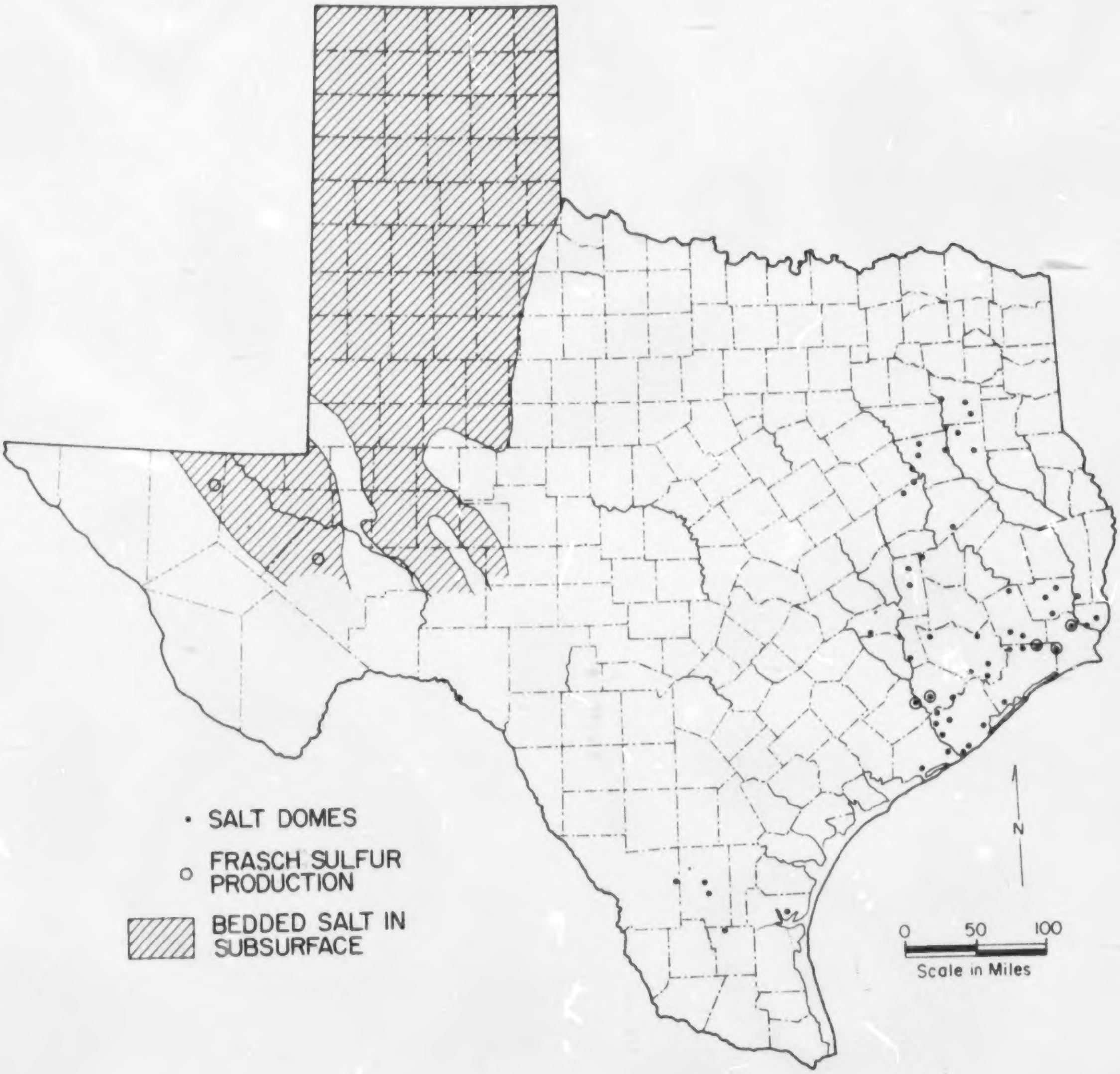
• SALT DOMES
○ FRASCH SULFUR PRODUCTION
▨ BEDDED SALT IN SUBSURFACE
N
0 50 100
Scale in Miles

Figure 9. DISTRIBUTION OF BEDDED SALT DEPOSITS AND SALT DOMES IN TEXAS

Sand and Gravel

Texas ranks third in the nation in the production of sand and gravel. In 1977, Texas sand and gravel operations exceeded 180 in number and produced over 52 million tons valued at $113 million. Sand and gravel was mined in 87 Texas counties (Figure 4).

Sand and gravel is produced for two major uses: construction and industrial applications (Table 5). Constructional sand and gravel is used in a wide range of building activities, including housing and nonresidential construction, road building, and dam and bridge construction. It is also used as fill material. Depending on the specifications of the proposed use, sand and gravel aggregate may be processed or unprocessed. Processed construction aggregate has been classified (screened) to a known range of particle sizes. Unprocessed aggregate has not been classified and is generally used in the same condition as it is removed from the ground.

Industrial sand and gravel is used for a variety of special applications and also is commonly known as specialty sands. (Gravel for industrial use is limited.) Industrial sand is used for sandblasting, as abrasives; in making glass and ceramics; and is used for sandblasting, as abrasives; in making glass and ceramics; and as fillers and foundary molds. The specifications that users require for industrial sands are generally very narrow and exacting. Factors such as chemical purity, size range of sand particles, and shape of sand particles are commonly included in the specifications required for specialty sands.

Sand and gravel is produced mostly from the alluvial deposits associated with rivers and streams in Texas. In addition, most sand and gravel pits are found close to urban centers reflecting the low unit value and high place value of this commodity. (Specialty sands, however, are high-unit-value commodities.) A map of active and inactive sand and gravel operations would show many hundreds of pits. Pit locations are often abandoned not because of exhausted sand and gravel resources but because construction sites change and move farther away from the production localities.

PROTECTION OF THE ENVIRONMENT—Sand and gravel pits are mined in a fashion superficially similar to lignite mines (Figure 6). Instead of big draglines, however, dredges or power shovels are used to mine the resource. Waste material is piled in long rows of conical spoil piles.

Current environmental regulations governing sand and gravel operations focus on maintaining high water quality in the streams commonly associated with the mine. The principal problem is excessive siltation of the stream. At this time, no pit-reclamation laws exist for sand and gravel operators, although some voluntary reclamation does occur as operators will occasionally level the rows of spoil.

Table 4. LIMESTONE PRODUCTION, AND VALUE IN TEXAS BY USE*, 1975

	Production (short tons)	Unit Value	Total Value
Aggregate, coarse (includes use as concrete, bituminous, macadam, roadbase, surface treatment, riprap, railroad ballast, and other aggregates)	40,552,653	$1.74	$70,466,253
Agricultural lime	242,235	1.57	381,146
Cement, portland and masonry	6,900,541	1.30	8,982,371
Fine-grind products (includes poultry grit, asphalt filler, manufactured fine aggregate, and whiting)	356,004	5.07	1,805,336
Fluxstone	361,776	3.43	1,241,961
Lime	1,918,362	1.79	3,435,188
Other uses (includes filter stone, terrazo, roofing aggregate, sugar refining, waste material, and others)	1,654,523	1.76	2,905,301
TOTAL	51,986,094	$1.72	$89,217,556

Table 5. SAND AND GRAVEL PRODUCTION IN TEXAS, 1975

	Quantity (thousand short tons)	Value ($1,000)
CONSTRUCTION AGGREGATE		
PROCESSED:		
Concrete aggregate (including use in ready-mixed concrete):		
Residential and nonresidential construction	17,099	38,700
Highway and bridge construction	4,516	10,066
Other construction	1,361	3,020
Concrete products	3,503	7,877
Bituminous paving	2,257	5,417
Road base and subbase	1,615	3,436
Fill	550	783
Other	87	188
UNPROCESSED:		
Road base and subbase	2,544	3,484
Fill	3,668	2,953
Other	131	174
INDUSTRIAL SAND AND GRAVEL	1,318	11,009
TOTAL	38,649	87,106

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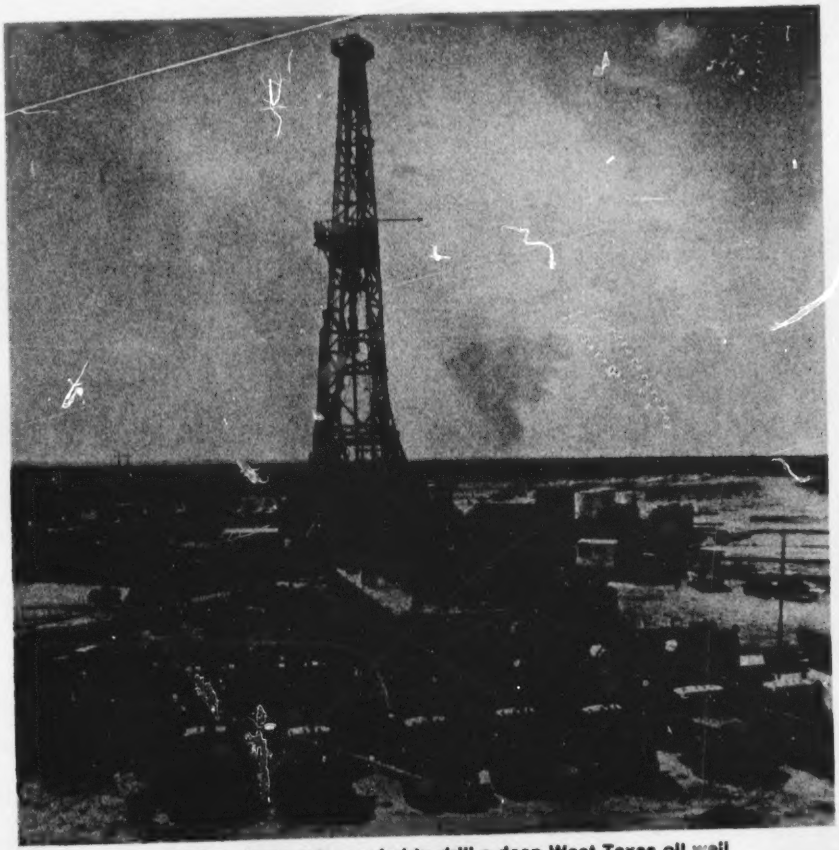
*Dimension stone is not included to preserve confidentiality of individual company data. In 1975, three quarries produced both rough and dressed limestone dimension stone.

Oil and Gas Resources of Texas

One has only to look at the history of Texas since the turn of the century to see the impact oil and natural gas have had on the economic and social development of the state. Only 27 years after the great Spindletop discovery in 1901, Texas became the number one oil producing state in the nation. By 1932, the value of oil and gas production exceeded the value of the agricultural output and has remained the undisputed leader ever since.

THE SEARCH FOR OIL AND GAS

The search for oil and gas in Texas began just after the Civil War, and some production was developed prior to 1900. One of the earliest efforts to find oil was in 1866 when Lyne Taliaferro Barret bored a well with an auger powered by a steam engine near an oil spring in wooded Nacogdoches County. While oil, water, and gas were found at a depth of 106 feet, the well produced only 10 barrels of oil a day. Later attempts were unsuccessful and Barret abandoned the search. Two decades later another attempt in Nacogdoches County created a small boom when oil was found. Oil was being discovered in other parts of the state, too, and oftentimes by accident. Corsicana was one of the areas that profited when oil was discovered in 1894 while drillers were attempting to find water. However, it was Spindletop near Beaumont, the gusher that spouted oil for nine days, that made Texas world famous as a petroleum area.



Extensive equipment is needed to drill a deep West Texas oil well.

102

In time, one great field after another was discovered. A water well drilling crew on the W.T. Waggoner Ranch in Wichita County hit oil bringing in the Electra Field in 1911. In 1917, the Ranger Field in Eastland County was discovered to be followed by the Burkburnett Field in Wichita County in 1919. The Mexia Field in Limestone County followed in 1920. Oil and gas discoveries in the Panhandle were registered in 1921. The Luling Field in 1922 and the comeback of Spindletop in 1925, with production greater than before, marked these years. Other famous fields opened in this period including Big Lake, 1923; Wortham, 1924-25; and, the Yates Field in 1926.

The East Texas field, biggest of them all, was discovered by veteran wildcatter C.M. "Dad" Joiner in October 1930. Subsequent significant production were wells in West Texas following the discovery well in Scurry County in 1948.

Through the years, petroleum resources have linked with demands of society and today account for 75 percent of the U.S. energy supply. Texas crude oil wells alone account for about 38 percent of all the energy needed to turn the nation's wheels and heat its homes.

In Texas, the industry encompasses all phases: the search for oil and gas, development, production, refining, transportation, and marketing.

The industry's $1.7 billion payroll is among the state's largest. Its refineries and petrochemical plants account for a major share of Texas manufacturing. Its thousands of oil and gas wells produce in 212 of the 254 counties. In 1978, the value of Texas crude oil, natural gas, and gas liquids was $18.9 billion. This was shared with thousands of farmers, ranchers, and others who are royalty owners for production from their land.

EXPLORING FOR OIL

Until the oil well driller's bit finds them, these fluid minerals lie trapped within the tiny pores of sedimentary rocks buried thousands of feet below Texas plains, forests, and Gulf shores.

The origin of oil and gas in the sedimentary layers, according to most geologists, can be explained by the so-called organic theory. This theory holds that crude oil is an organic mineral formed by the decay and alteration of the remains of prehistoric marine animals and plants.

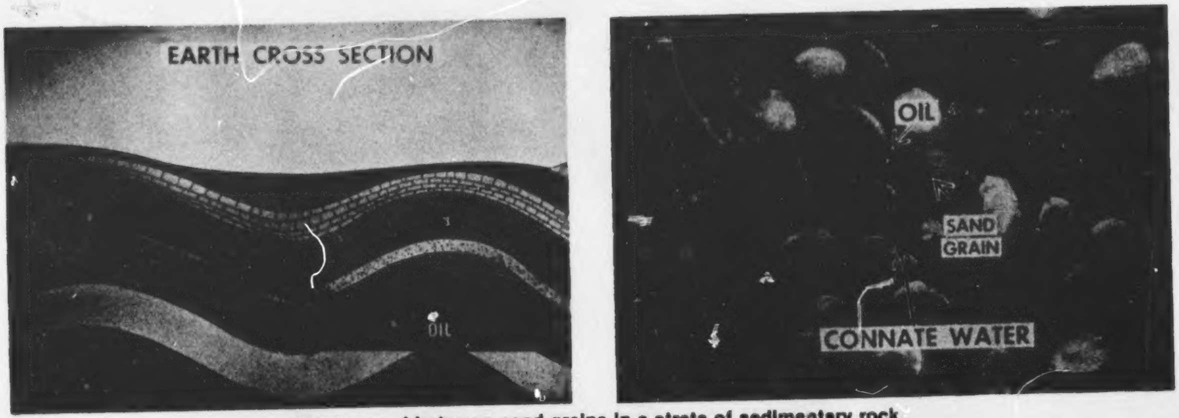
Oil is most often found in sediments laid down in ancient seas. These seas once covered much of the continental land area that we now know. The residue of plant and animal life settled to the bottom of the ancient seas and accumulated there, layer atop layer. As the old layers become buried deeper and deeper, they were compressed by the tremendous weight gathering above them. Under this pressure, heat was generated. Other factors—chemical, bacterial, and radioactive—entered into the process. Together, these gradually reformed the organic matter into the compounds of hydrogen and carbon that we know as petroleum.

Gas and oil are lighter than water. So after they formed, oil and gas tended to rise upward through the water that filled the porous spaces in the sedimentary formations. Where a formation of dense, nonporous rock lay above a porous layer, the migration stopped, and there oil and gas collected. Gas the lightest, filled the small voids present in the upper parts of the porous rock layer. Oil settled beneath the gas. Water, the heaviest, remained in the lower areas. Originally, the deposits were laid down horizontally. But, through the centuries, movements and strains in the earth's crust folded or broke them. Seas shifted. Continents were formed. Mountain ranges appeared, and ancient sea bottoms became dry land areas.

These changes and upheavals often caused shifts or breaks in the rock layers creating traps that collected migrating oil and gas. These are the layers of oil-filled rock identified by geologists as the Ellenburger, Sprayberry, Wilcox layers, among others. The most common types of trapping geology are faults, anticlines, and stratigraphic traps.

An anticline is an arch-like upward fold in the earth's strata. This is perhaps the most common oil trap, and most of the world's known oil deposits are found in anticlines.

A fault can be described as a fracture in the earth's crust that shifts a nonporous layer next to a porous one, cutting off the porous layer.



Oil is trapped between sand grains in a strata of sedimentary rock.

A stratigraphic trap is a formation in which the trap is formed as a result of thinning or permeability degradation in the reservoir rock or a break in its continuity. Often described as pinch-outs, these traps are found in many areas of Texas. Perhaps the most famous is the East Texas field which is a series of thin, lens-like interconnected sands capped by a layer of impermeable chalk.

Oil and gas are frequently found adjacent to, or on top of, an underground salt dome. This type of structure results from the upward thrust of a great mass of salt far below the earth's surface. When a salt dome rises through a layer of oil-bearing sedimentary rock, oil may be trapped above the salt dome or in structures along its flanks.

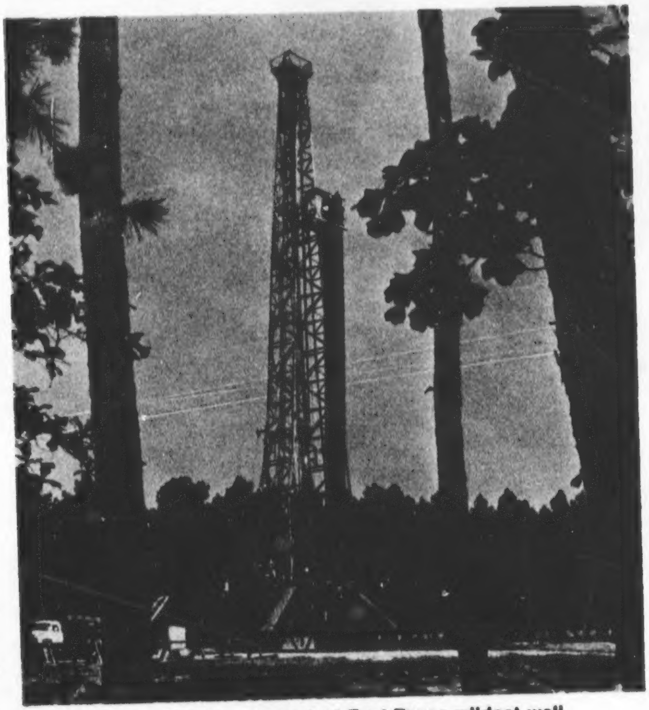
Geologists and geophysicists in their search for oil-bearing sedimentary strata use several instruments. After careful study of rock formations, of outcropping of strata that have been exposed by erosion, and of other geological data, a magnetometer, gravimeter, and seismograph are used to provide a more detailed picture of the subsurface formations. The magnetometer measures variations in the earth's magnetic field. Sedimentary rocks generally have low magnetic properties compared to other rocks that are high in minerals or more dense. The gravimeter measures minute differences in the pull of gravity at the earth's surface. Because large masses of dense rock increase the pull of gravity, gravimeter readings at a number of surface points provide a key to underlying structural conditions. The seismograph, originally developed to record earthquakes, is now also widely used as an oil prospecting tool. Vibratory or percussion devices create sound waves that travel downward, striking successive rock formations and are reflected back to the surface where they are recorded. By correlating the intensity of the waves and the time intervals required for them to travel down and back, the geophysicist learns the general characteristics of the undergound structure.

Should all preliminary reports be favorable, they simply indicate the possibility of finding oil. Only drilling into the formation will prove whether oil exists. Nationally, the odds are weighted 10 to one against the possibility of finding oil or gas—and 50 to one that the petroleum will be found in commercial quantities based on present crude and gas prices.

CRUDE OIL PRODUCTION

To find oil and gas and convert these natural resources to people's use, the Texas petroleum industry employs some of the most advanced industrial and scientific techniques in existence.

New oil fields and new producing formations are found by "wildcat wells" drilled in untried territory or at unexplored depths. More than 3,800 "wildcats" were drilled in Texas in 1978. The risk involved in hunting for oil and gas is shown by the fact that more than 70 percent were dry holes.



Drilling begins at a typical East Texas wildcat well.

The search for oil requires vast sums of money because the only way to prove whether an area may be productive is to drill a hole. The cost of drilling for oil varies widely in Texas, depending on the area, kinds of formation, and depth. The average on-shore well has been calculated to cost more than $240,000 with the per-foot cost around $43.45. A well drilled in the Gulf of Mexico averages $1,691,564 per well—seven times the cost of an on-shore well.

Texans drilled 15,037 wells in 1978, including 290 test and service wells. This was 31 percent of all U.S. drilling. In all, some 78 million feet of hole were drilled in Texas in 1978.

Crude oil production has a widespread effect in Texas. Fields are scattered over the whole state and ownership of oil is split among many interests. The fields themselves range in size from those trickling a few barrels a day to some of the largest that can yield in excess of 150,000 barrels a day. Today, more than 5,500 companies and firms are engaged in the oil business, operating more than 182,159 oil wells in more than 9,110 fields. Sharing in this operation, of course, are thousands of landowners who receive rental and bonus money by leasing their acreage for drilling. When production is found, they become "royalty" owners and receive about one-eighth of the state's crude oil crop. In 1978, Texas landowners received some $2 billion as their share of Texas oil and gas production. In 1978, the Texas Permanent School Fund received $267.5 million from the industry for lease rentals, bonuses, and royalty payments; since 1932, $1.7 billion. From this same source, The University of Texas Permanent Fund received $96.9 million; since 1924, $1 billion.

While Texas is the leading oil producing state, competition from other oil producing states and countries has reduced its world position in recent years. Texas produced about 1 billion barrels of crude in 1978 which was about 4.9 percent of the world's output. (In 1950, Texas produced 22 percent.)

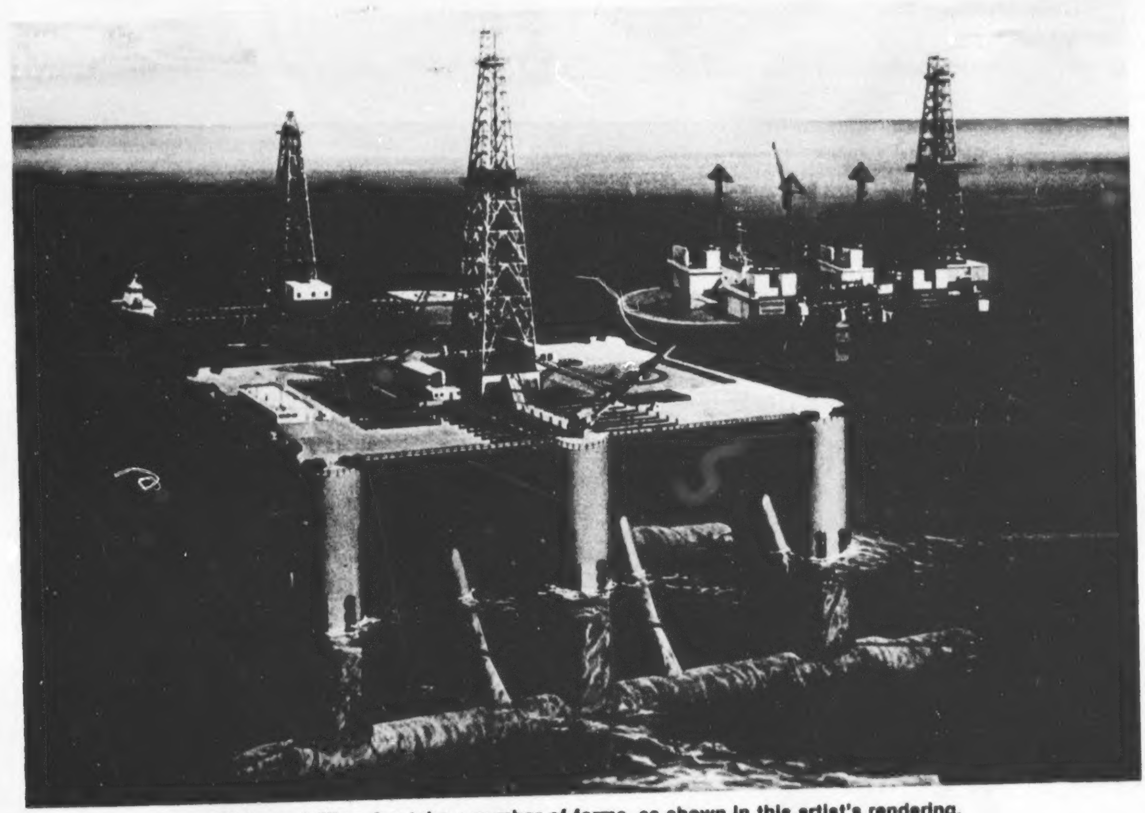
Environmental Procedures

Environmental concern in the exploration and production of oil and gas demands large sums of money, and millions of dollars are spent annually in pollution research leading to pollution control. In exploratory work, for example, the seismograph is used to measure sound waves for mapping underground structures that might contain oil and gas. To create sound waves, dynamite is detonated in shallow shot holes. As an alternative to this method, seismic operations now utilize nondestructive energy sources such as weight drops, gas fired chambers, or hydraulically operated vibrators to produce echoes without damaging the land surface or endangering wildlife. For offshore work, an air gun discharges compressed air to create seismic echoes. These guns are harmless to fish and other marine life.

In drilling and production, whether on or offshore, casing is set in the hole to protect subsurface fresh water zones and the space between the hole and the strata is filled with cement to prevent fresh or salt water from escaping. If a well is abandoned, the casing is plugged with cement at the bottom and the top of the hole to prevent flow of any liquids up the hole, thereby preventing future pollution of ground level water supplies.

The policy of companies drilling offshore is not to allow pollutants to fall into the sea. Impervious steel decking is used on both drilling rigs and production platforms. Drip pans and sumps catch oil wastes that are pumped to skimming tanks and water treaters. Trash, garbage, and other waste from drilling operations are hauled ashore by boats and barges.

Hostility of the sea requires that offshore rigs and production platforms be strong enough to withstand extreme wind and wave action. Flowlines are buried wherever there is a possibility of their being snagged by anchors or nets. Navigational bouys and foghorns are also used.



Offshore drilling rigs take a number of forms, as shown in this artist's rendering.

Offshore wells are equipped with emergency valves to automatically stop the flow of oil or gas in the event of a rupture in the flowline. Such equipment is resistant to corrosion or is specially treated.

In many oil fields, salt water is produced along with the crude oil. To avoid contamination of fresh water and land productivity, salt water is:

- pumped into underground formations beneath, and separated from, fresh water strata. Exhausted wells and dry holes are often used for salt water disposal. If unavailable, disposal wells are drilled.
- injected into oil reservoirs for secondary recovery purposes or for more efficient recovery of oil from new fields
- safely released into drainage systems and coastal water when of better quality

Fields producing salt water utilize equipment to separate oil and solids from brine before being pumped back into disposal wells.

To develop better methods of prevention and control of oil spills in rivers, bays, and estuaries, local cooperatives have been formed throughout the United States and many more are in the formation stages. Oil spill control methods have included the use of dispersants, sorbent materials, burning aids, sinking agents, and biological agents. Containment devices used in the water include floating booms or barriers, skimmers, plastic tents or bubbles that trap oil above the leak, and the pneumatic air barrier system (used mainly in harbors or slow-moving streams). Six oil spill cooperatives, equipped and staffed with trained personnel, have been formed in Texas. The cooperatives are located in the Beaumont-Port Arthur-Orange area; in the Houston-Galveston area; and in the near Corpus Christi.

THE ENERGY SHORTAGE

High costs, disappointing results, and relatively low oil prices for more than a quarter of a century slowed the search for oil from the peak year of 1956 when more than 21,500 wells were drilled to a low of just over 11,000 in 1968. As U.S. energy demand increased, "cheap" imported oil replaced domestic supplies. In 1971, Texas refineries were processing foreign crude for the first time. By 1972, it was no longer necessary to restrict Texas' production to market demand and prorate that amount among producers, as provided by law. The wells could now produce at 100 percent of their rated capacity, i.e., a maximum rate of flow that did not damage reservoir pressures and cause underground waste of oil and gas. It became readily apparent that an energy shortage of enormous proportions was developing as the nation moved from an era of abundance in petroleum energy to one of dependence. Through the years, while Texas oil producers were warning of impending shortages, consumer demand for oil and its products moved steadily upward as price-controlled domestic oil declines. (Crude oil and petroleum products were put under price controls in 1971.)

In 1973, events in the Middle East precipitated the growing energy shortage to one of crisis. A cartel of foreign oil-producing countries (OPEC), because of U.S. support of Israel in the Arab-Israeli war, suddenly announced an embargo on oil shipments to the U.S. and other countries sending supplies to Israel. The embargo came at an unfortunate time as burgeoning demand had increased imports in 1973 to an all-time high of 35 percent, an increase of 20 percent over 1966. The result was a shortage of oil for this nation and the world.

The easing of the embargo by the OPEC cartel in March 1974 was coupled with a drastic rise in the price of oil in world markets, some exceeding 400 percent. By 1979, U.S. dependency on foreign oil had reached nearly 45 percent of daily demand, and the imported price had increased from $1.85 to $23.50 a barrel. Of significance, the state's economic and industrial activity was being affected by two emerging trends:

- The slow decline in daily output was reflecting the strain placed on older oil fields in trying to maintain a consistently high production level.

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- High prices for both newly discovered oil and additional oil produced through modern recovery techniques were stimulating the search for oil and natural gas in Texas.

The possibility of reviving older—sometimes abandoned—producing areas was being evaluated, and wildcat drillers were probing in places considered too risky to explore under economic conditions that existed even two years before.

FEDERAL AND STATE REGULATION

The amount of crude oil that can be sold and the price per barrel are important to Texas. They represent a large item in the state's economic output and affect the general business picture. Currently domestic oil is subject to a price control system authorized by the Energy Policy and Conservation Act that is administered by the Department of Energy.

Nationally, and in Texas, the average price for all domestic crude oil is subject to a composite price limit. Under certain provisions, the price limit can be adjusted upward due to inflation and/or as a production incentive when approved by the President and either house of Congress. Under price controls in 1979, the average price per barrel of U.S. oil was $14.74.

Other major petroleum provisions of the Energy Policy and Conservation Act include storage of strategic petroleum reserves, standby energy emergency authority, conversion of oil- and gas-fired utility and industrial boilers to coal, and automobile efficiency standards. Energy legislation approved by the Congress and signed into law by President Carter in 1978 continued the policies of a previous Act with one very significant change. The Natural Gas Policy Act of 1978 extended price controls to gas sold in the intrastate market. (Since 1954, federal price controls had been limited to gas sold only in the interstate market.)

In Texas, every barrel of oil is produced under one of the most comprehensive systems of conservation ever devised for protection of a natural resource. At the heart of such a system is the necessity for making the best use possible of the underground pressures from the water and gas that push oil through the rock to the well bore. Too many wells or too rapid production in a field exhausts these vital pressures, leaving oil trapped in the rocks and wasted. In Texas, there is public regulation of the way wells are spaced in a field and the rate at which oil is produced.

The Oil and Gas Division of the Texas Railroad Commission is the state agency charged with the responsibility of regulating the oil and gas industry for the purpose of conserving petroleum, preventing its waste, providing for equitable production among operators, and protection of fresh waters from pollution by oil and gas. The agency's authority is illustrated by the fact that it determines the amount of oil or gas that individual wells may be permitted to produce, the conditions under which they may be operated, and methods, primary and secondary, under which they may be produced.

NATURAL GAS PRODUCTION

One of the principal sources of vitality in Texas economy is the abundance of natural gas. Texas not only is the nation's largest producer of gas, but it is likewise the largest consumer. More than 65.5 percent of Texas gas production is used in Texas, the remainder being sold to other states. The majority of lights and electric motors in Texas are supplied with electrical energy converted from natural gas. More than two million Texas homes use gas for cooking and heating. Texas industrial plants depend on gas for more than 90 percent of their local energy.

The oil wells themselves are a source for about one-fourth of the state's gas production, for there is some gas in every oil field. The rest comes from wells that produce only gas. There are more than 33,000 gas wells in Texas and 165,300 oil wells that produce gas for market. Six-and-a-half trillion cubic feet of gas were marketed from Texas wells in 1978.

Texas gas reserves totalled 62.3 trillion cubic feet at the end of 1977, or 29.8 percent of the nation's reserves.

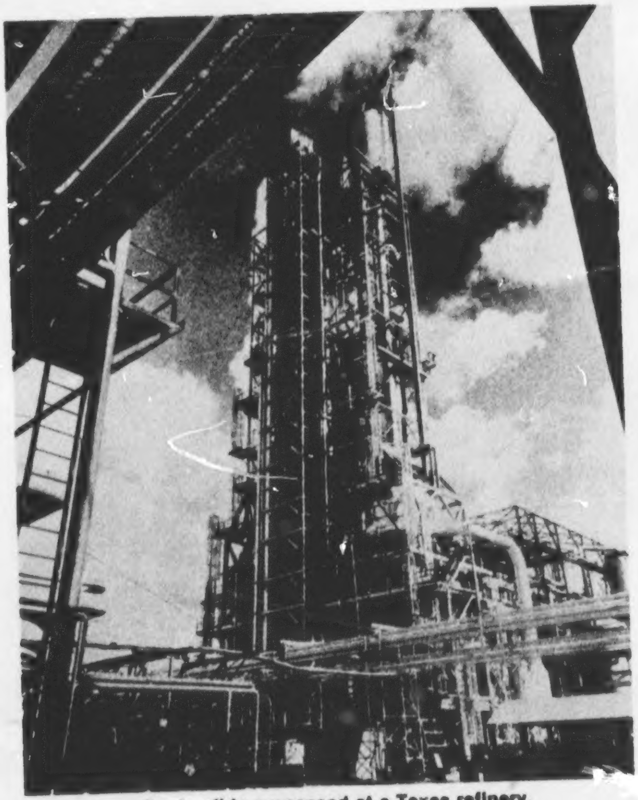
Increased recovery from gas of valuable liquid fuels (such as butane, propane, and natural gasoline) has given Texas gas operations additional importance in recent years. Texas has in excess of 400 plants in gas fields that extract these liquids.

In handling gas resources, Texas has made great progress in conservation. Prior to World War II, the price of gas was so low that much of it produced with oil (called casinghead gas) was burned in the fields to get rid of it. Little of the total production is wasted today. Improved prices in the intrastate market provided the incentive needed to push gas producers into the more risky formations that would have been uneconomic prior to 1972; and such efforts resulted in many new gas fields in the state.

REFINING AND PETROCHEMICALS

On the coastal plains of Texas, the towering steel cylinders of the refineries and petrochemical plants symbolize a major portion of the state's manufacturing industry. For here nearly a third of the nation's petroleum products are made--including the fuels which propel America's cars and planes and which heat millions of homes. In addition, the chemicals that are transformed into today's plastics and fibers are extracted from oil and gas in these towers and coils of pipe.

With its 55 refineries, Texas processes more oil than any other state. The Texas plants, most of which are clustered about the principal Gulf ports, have a total capacity of some 4.7 million barrels a day, or 27.4 percent of the nation's total. They range in size from those handling a thousand barrels of crude oil a day to those running close to 350,000 barrels each 24 hours.



Crude oil is processed at a Texas refinery.

Texas refineries process an amount of crude oil equivalent to 94 percent of the crude oil produced in Texas, thus giving the state added economic benefit in its natural resources. Although relatively few employees are required to control the sprawling complexes of refineries and chemical plants, there are some 41,000 Texans engaged in refining alone. Significantly, their wage scale, averaging $9.77 an hour, in 1979, is one of the highest in the state.

Environmental Procedures

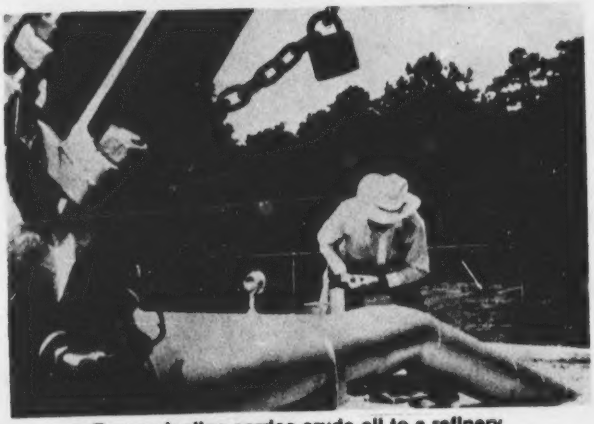
Stringent environmental protection methods are employed in the refining of petroleum products. As refineries use vast amounts of fresh and salt water in making products, conservation practices are aimed at maximum utilization of water and purification of process water before it is used again or returned to rivers, streams, or bays. Process water requirements have been reduced to as low as one and one-half barrels of water to one barrel of crude. All process water picks up hydrocarbons and chemical contaminants. Two of the chief chemical contaminants are caustic and acid which are recovered and sold. Water containing hydrogen sulfide, phenols, ammonia, and other chemical compounds (called "sour water") is treated separately by stripping or oxidizing sulfides and ammonia.

If economically feasible, these compounds are recovered or burned in furnaces where local air pollution codes permit. Oxidized compounds are converted to nontoxic compounds that can be diluted and discharged with effluent water. Sour water also can be pumped down disposal wells into salt water strata below fresh water tables. After recovery of compounds, oil is recovered and reprocessed. Oily waste water is then sent to a gravity separator where oil is removed from the top and sludge from the bottom.

Gravity separators leave minute amounts of oil in water, which is then chemically treated to form a floc of suspended oil particles. Floc precipitates out of the effluent water. To remove remaining contaminants, water is pumped into large, lined aeration ponds or lagoons to be treated biologically. Oxygen is added by aerators, rotating brushes, or by dissolving (under pressure) air in the water. The latter process results in the release of bubbles that attach to oil and solids and rise to the top for skimming. Oxygenated water is then released. Refineries check constantly on oxygen content of released water to assure that marine life is not harmed by water with low oxygen content. Even storm water (rainfall) is gathered from refinery grounds and processed to remove oil.

Final tests of effluent water includes a bioassay test, which may involve placing fish in test tanks and observing their reaction to the water. This can serve as a basis for judging whether water is suitable for discharge. Water is discharged with effluent oil content of less than 50 parts per million.

Sludge, which cannot be reprocessed, is spread over open refinery land and left fallow for several months. Its decomposition by soil bacteria allows vegetation to return. If land area is not available, sludge is degritted, dewatered, and charged to an incinerator from which the ash is hauled off for landfill.



Texas pipeline carries crude oil to a refinery.

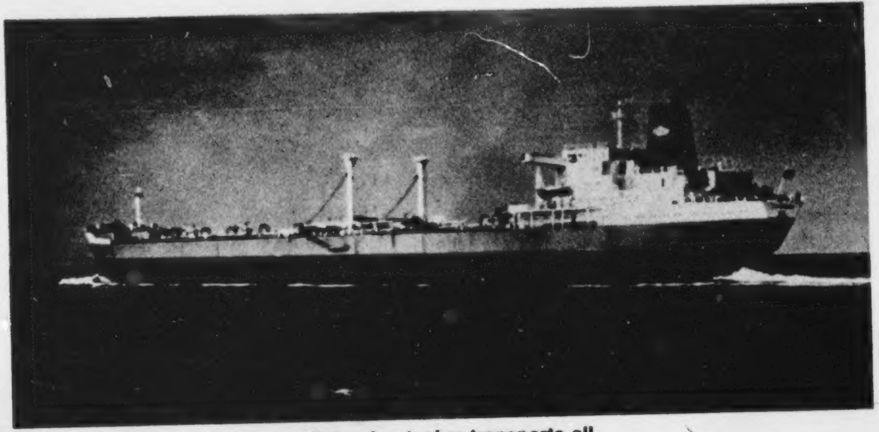
TRANSPORTATION

Every 24 hours the Texas petroleum industry must move more than half a million tons of oil from thousands of fields to the refineries and then move about that amount of finished oil products into supply lines that sustain the American lifestyle.

To link the most remote West Texas oil well with the consumer's gasoline tank, the industry relies on many forms of transportation—pipelines, rail tank cars, trucks, barges, and ocean-going tankers.

The heaviest part of this great transportation task, however, is handled by the industry's network of oil and gas pipelines totalling some 173,392 miles in Texas. About 36,723 miles of these lines are the smaller systems that gather oil from the wells and deliver it into the big trunk lines. These are the main arteries of the whole industry. Another network carries the refined products to terminals and other distribution points for truck, barge, or tanker movement.

The size of the petroleum transportation industry in Texas is seen in the fact that two out of every three tons handled in Texas harbors are crude oil or oil products. Texas has 12 ports served by ocean-going vessels.



Sea-going tanker transports oil.

Environmental Procedures

Extreme environmental diligence and care are the watchwords in transporting oil, gas, and petroleum products. Pipelines are constructed of high quality steel and are pressure tested above operating requirements. Pipelines are coated and wrapped with corrosion-resistant material, equipped with cathodic protection systems, and laid far below plow depth and even deeper at road crossings.

At water crossings, heavier pipe is installed, coated with concrete to prevent buoyancy, and buried at sufficient depth to prevent fouling by draglines, dredges, or ship anchors.

Existing river crossings are inspected periodically for bank erosion, bottom scour, and changes in the river's course. If conditions warrant, new pipe is laid. Dredging of navigable rivers may require the existing line to be buried deeper or new line to be laid at proper depth.

Through a United Nations organization, the United States and 32 other countries set rules allowing tanker discharges of oily ballast into the sea. However, the marine transportation segment of the United States petroleum industry has elected not to discharge oily substances into the sea, even where permitted by international law.

When emptying ballast (salt water pumped into empty cargo tanks to achieve stability at sea), the last three feet of water (containing oil on top) is held in the tanks and pumped into collection tanks ashore. Major ports such as those in the Houston-Beaumont-Texas City areas, have deballasting facilities. When loading or unloading, line connections are made leakproof before pumping begins; loading hoses are checked for leaks and replaced periodically.

At some docks, oil spills on the dock are carried into a rain water drainage system that delivers the oil to a separator on shore.

MARKETING

To provide fuel, lubrication, and accessories for millions of motorists, the petroleum industry maintains more than 9,833 service stations in Texas. Texas is also one of the country's major users of products from its own oil and gas wells. Texas consumes 8.7 billion gallons of gasoline a year, ranking second behind California.

Environmental Procedures

Marketing represents the final major environmental concern to the industry in delivering this volatile fuel to consumers. Terminal storage tanks for gasoline and other "light" products are equipped with sealed floating roofs to minimize loss of hydrocarbon vapors into the air.

These large tanks are encircled with earthen dams (dikes) to contain liquids that might spill from the tank. Both storage tanks and loading equipment have slop-oil drainage systems and oil-water separating equipment, where necessary. Terminals may also use separating ponds to handle run-off water that might contain oil. Automatic stop valves and shut-off valves protect against product spillage.

Underground product tanks and piping at service stations are pressure tested and made corrosion resistant before installation. In addition, all stations are equipped with automatic cut-off nozzles to prevent auto tank overflow.

Service stations serve as the major collecting agency for waste oil from automobiles. Waste oil is collected and held at each station until disposed of in accordance with local codes or proper company procedures. It is not dumped into sewer systems. Some waste oil is reprocessed. Other oil disposal methods include the use of waste oil as fuel, after blending with heavier fuel oils.

OIL AND GAS RESERVES IN TEXAS

The industry's exploration and development investments in Texas have uncovered oil sources that have sustained an average of one billion barrels of production annually during the last decade. The state still has oil reserves of approximately 10 billion barrels. About 7.7 billion barrels of these reserves are crude oil and 2.3 billion barrels are liquid fuels that can be extracted from natural gas. A little more than 27.6 percent of the oil reserves of the United States are in Texas. Only the oil that can be recovered under today's methods of recovery and prices is counted in reserve estimates. Actually, there are additional billions of barrels in these same Texas fields that can be produced by more sophisticated production methods but at a much higher cost.

Texas crude oil and natural gas reserves are at the lowest point since 1945. Natural gas reserves have dropped 70.3 trillion cubic feet (57 percent) from the peak year in 1967; crude oil reserves have declined 7.6 billion barrels from the 1951 all time high.

One of the main uses of petroleum is in the form of fuel for transportation. Transportation uses half of the total oil consumed in the United States. Conservation strategies are needed in order to prolong the amount of time available before present fuel reserves are exhausted. Conservation also includes the use of alternative sources of energy that are not presently in danger of diminishing including solar and wind. The problems of energy consumption, development, and conservation must be addressed to ensure the wise use of our energy resources on which depends the quality of life in our state and nation.

Water Resources of Texas*

Water is essential to every phase of the Texas economy. Farmers and ranchers need water for crop and livestock production; city dwellers and rural inhabitants need water for domestic consumption and sanitary purposes. Many industrial plants use large amounts of water in their manufacturing processes. Water is converted to steam and used to generate electrical power; additional water is used in steam power plants for cooling. Hydroelectric power is produced from the energy of falling water. Timber and lumber interests depend upon water in the form of rain for production of their basic resource and for prevention of forest fires. The state's recreational assets include its streams, lakes, and reservoirs. Fish and wildlife depend on water for their existence.

GENERAL CONSIDERATIONS

Texas water resources consist of precipitation and streamflow, together with the water stored in the soil, in ground-water reservoirs, and in surface reservoirs. As shown in Figures 1 and 2, water resources are derived from precipitation, which consists almost entirely of rainfall, together with varying amounts of snow, sleet, and hail. Some precipitation returns directly to the atmosphere through evaporation from vegetation, the land surface, and people-made developments. A large part enters the ground, and the remainder provides the flow of the state's extensive network of streams. The streams lose some of their water through evaporation and seepage from their channels. Substantial amounts of streamflow are diverted into canals and pipelines for municipal, industrial, and agricultural use or are intercepted by numerous reservoirs that have been created throughout the state. By far the largest part of the flow of Texas streams, however, escapes into other states or the Gulf of Mexico.

Some precipitation that enters the ground is retained in the upper few feet of soil and provides a natural water supply for crops, trees, grasses, and other vegetation. Most of this water eventually returns to the atmosphere through transpiration by growing vegetation and evaporation from the uppermost soil layer. Precipitation percolating past the root zone continues downward until it reaches material that is either impermeable or already saturated with water. This subsurface water that is beyond the reach of vegetation is the state's ground-water resource. Some ground water returns to the surface in springs and seeps and becomes part of streamflow.

Texas water resources are constantly changing in quantity, quality, form, and distribution because of climatic factors, use of water by vegetation, and human activities. Precipitation at any particular point varies widely from day to day, from month to month, and from year to year. At any particular time, it varies widely in amount and occurrence from place to place throughout Texas. This variability in precipitation is reflected most directly in the state's streams, whose flows may change from a trickle to a major flood, often in a matter of days and sometimes in only a few hours. As a result, the dependable water supply obtainable from the natural flow of a stream usually is only a small percentage of the average annual flow. Development of reservoirs substantially increases the dependable supply by holding back for later use flood waters that otherwise would discharge into the Gulf of Mexico.

A similar function is performed by the upper soil layers, or soil-mixture reservior, that stores precipitation for subsequent use by vegetation. Ground-water reservoirs, when tapped by wells, also provide water supplies. These supplies are considered dependable only when withdrawals do not exceed the average annual amount received by the ground-water reservoir from precipitation.

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*Additional information is available from the Public Information Office of the Department of Water Resources, P.O. Box 13087, Capitol Station, Austin, TX 78711.

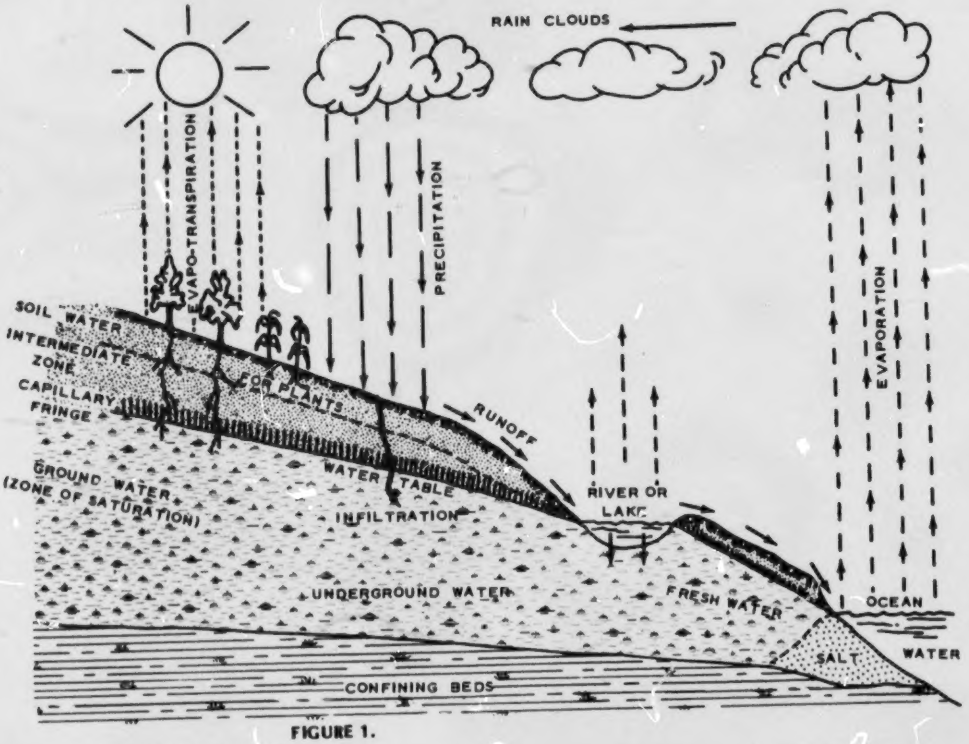

RAIN CLOUDS
EVAPO-TRANSPIRATION
PRECIPITATION
EVAPORATION
SOIL WATER
INTERMEDIATE ZONE
CAPILLARY FRINGE
FOR PLANTS
RUNOFF
RIVER OR LAKE
WATER TABLE
GROUND WATER (ZONE OF SATURATION)
INFILTRATION
UNDERGROUND WATER
FRESH WATER
OCEAN
SALT
WATER
CONFINING BEDS

FIGURE 1.

HYDROLOGIC CYCLE

This underground water illustration is not applicable where surface soils are water tight.

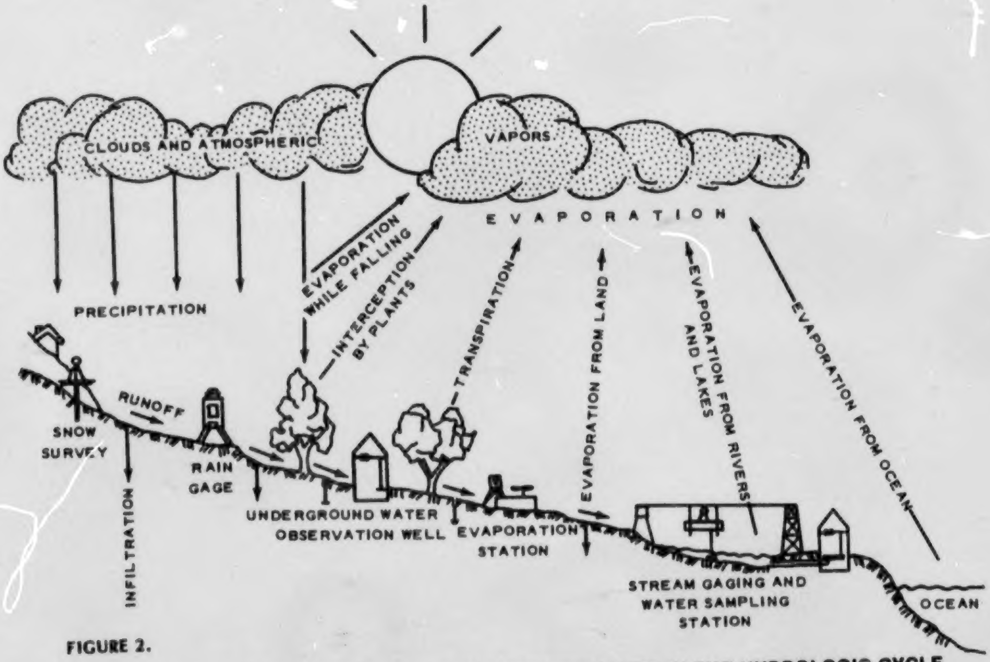
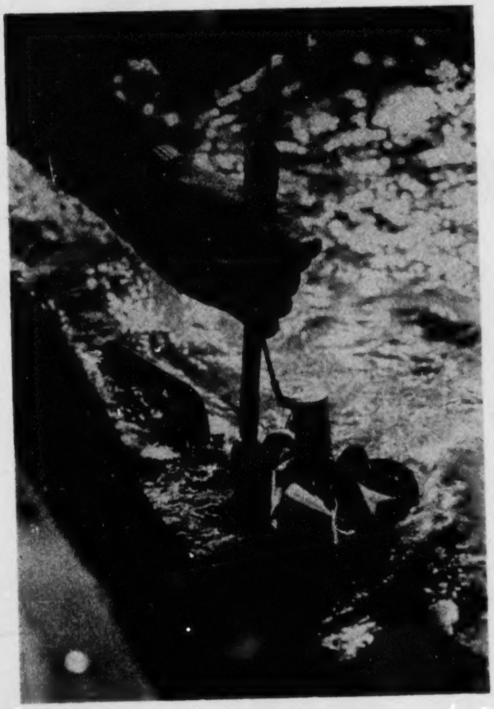

CLOUDS AND ATMOSPHERIC
VAPORS
EVAPORATION
PRECIPITATION
EVAPORATION WHILE FALLING
INTERCEPTION BY PLANTS
TRANSPIRATION
EVAPORATION FROM LAND
EVAPORATION FROM RIVERS AND LAKES
EVAPORATION FROM OCEAN
RUNOFF
SNOW SURVEY
INFILTRATION
RAIN GAGE
UNDERGROUND WATER OBSERVATION WELL
EVAPORATION STATION
STREAM GAGING AND WATER SAMPLING STATION
OCEAN

FIGURE 2.

DEVICES FOR MEASURING IMPORTANT FACTORS INVOLVED IN THE HYDROLOGIC CYCLE



Water engineers use different methods of gaging stream flow.

Because of the erratic occurrence of precipitation, farmers and ranchers never can be certain that the soil-moisture reservoir will provide adequate water supplies for crops and range vegetation. Irrigation provides the solution to this problem wherever additional water can be obtained from natural streamflow, ground-water reservoirs, or surface reservoirs, and where the land is suitable for the practice of irrigation. During the past 30 years, increasing awareness of the advantages of irrigation has resulted in a tremendous increase in irrigation in Texas, which ranks second only to California in irrigated acreage. Unfortunately, about 70 percent of this acreage is being supplied by ground-water withdrawals in excess of the average annual replacement from precipitation. In such areas, it will be necessary to stop irrigating when the present practice of pumping water previously stored in ground-water reservoirs for hundreds or thousands of years is no longer practical.

Until recent years, municipal and industrial water requirements in Texas were not great, and no serious problems were encountered in supplying them, from either ground water or relatively small surface reservoirs. Since World War II, however, Texas has experienced a sharp increase in population; a marked rise in per capita water consumption; a tremendous industrial expansion, such as oil refining and chemical manufacturing; and a large increase in irrigation farming. Because of these factors, development of adequate municipal, industrial, and agricultural water supplies has become one of the state's most pressing problems. Effort and money have been expended to create new supplies. However, anticipated future increases in requirements are so great that additional supplies will be needed to prevent impairment of the state's economic growth by actual or prospective water shortages.

Although within the borders of Texas there are enough water resources to satisfy all foreseeable needs for the state, the water is not always available. Nor can it reasonably be made available at the points of need and in the quantities required.

Studies by the Texas Water Development Board during preparation of the Texas Water Plan, a flexible guide for meeting Texas' water requirements to the year 2020, show conclusively that presently available water resources are inadequate to meet the state's future economically justified water needs. Importation of water from out-of-state sources will be essential. Without it, retrogression must inevitably occur in some sector of the state's economy, particularly in agriculture and associated agribusiness, with attendent social problems of unemployment, forced population relocation, and loss of financial investments.

SPECIFIC WATER RESOURCES

General Description

Texas occupies about 7 percent of the total water and land area of the United States. It has a land and water area of 267,339 square miles or 171,100,000 million acres of which 3,315,193 acres is inland water. The water picture in this area is highly diversified as a result of great variation in physiographic features, extreme climatic variations, and maldistribution of water.

In no other physical aspect does Texas possess such great variety as in its weather. The climate varies from subtropical in the lower Rio Grand Valley to middle temperate in the High Plains; from humid along the Louisiana border to arid in the Trans-Pecos area.

The flows of most Texas streams are of acceptable quality for all needs. Exceptions occur in portions of north and west central Texas and in the Pecos, Colorado, Brazos, and Red Rivers where stream flows are frequently too saline for domestic and many industrial purposes but are sometimes acceptable for irrigation, depending upon the character of the soils.

Texas ground waters are reasonably abundant but, as in other areas of the United States, are subject to depletion when great demands are placed upon them. The physics of underground reservoirs (aquifers) are such that the recharge of them, either by natural or artificial means, generally cannot keep pace when large volumes of water are withdrawn.

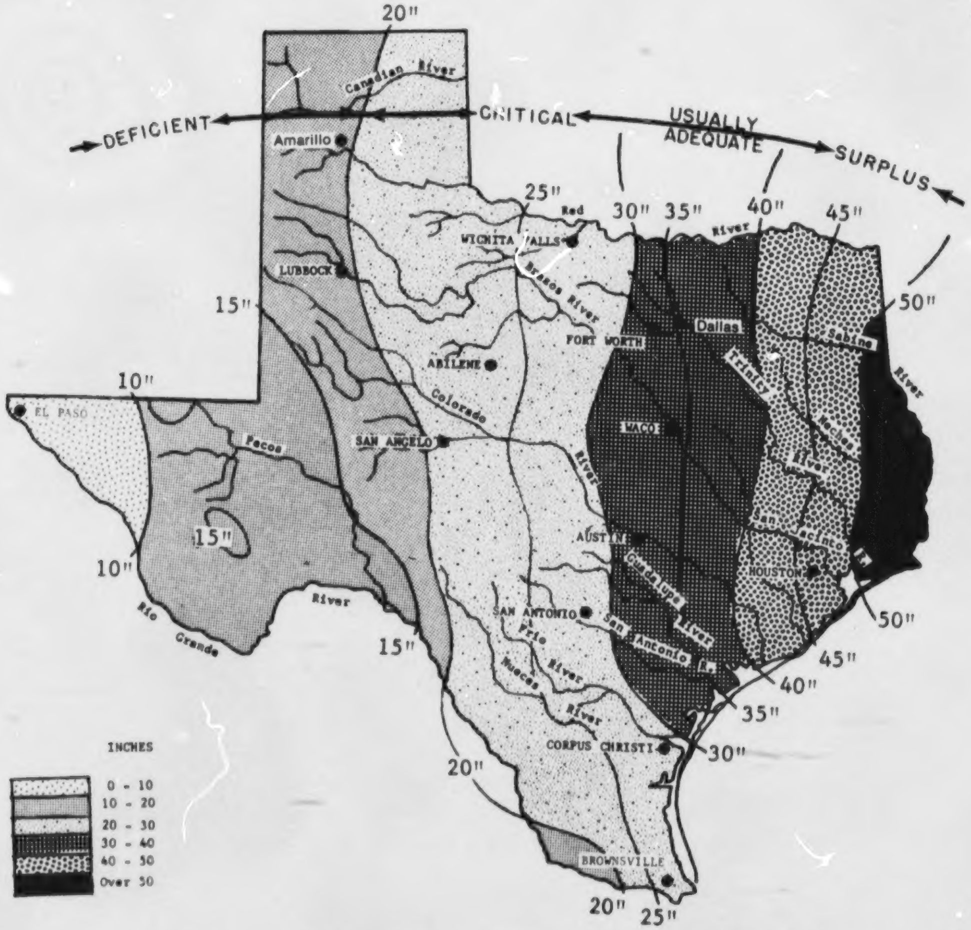
Precipitation

Precipitation, the sum of rainfall, sleet, hail, and snow expressed in inches, is the source of both surface and ground-water resources of Texas. It originates primarily from moisture evaporated from the Gulf and moved inland by prevailing southeast winds that meet the cooler air from the north and northwest.

Precipitation seldom occurs when, where, and at rates most needed. The greater portion of the annual rainfall in Texas usually falls within short periods of time, resulting in excess runoff and producing damaging floods. Droughts also occur periodically, and the combination gives rise to the description of Texas rainfall as being "either too little or too much, rarely just enough." The greatest amount of precipitation in one calendar year was measured in Anahuac in Chambers County, where 98.08 inches fell in 1946. The minimum annual rainfall was measured at Imperial in Pecos County, where only 1.95 inches fell in 1953.

Precipitation varies widely with geographic position and season of the year. Lines of equal average annual rainfall (isohyetal lines) fall in a general north and south direction, ranging from less than 10 inches in the extreme west to approximately 55 inches in the extreme east as shown in Figure 3.

The constant deviation of Texas precipitation from the average is reflected in the quantity of surface water available for use as well as in its capacity to become a destructive force. This factor is fundamental to the concept of physical works, such as dams and reservoirs, to provide reliable surface water supplies for beneficial use.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Canadian River
Red River
Brazos River
Colorado River
Pecos
Rio Grande River
Trinity
Neches River
Sabine River
San Jacinto R.
Guadalupe River
San Antonio R.
Frio River
Nueces River
Amarillo
LUBBOCK
WICHITA FALLS
FORT WORTH
Dallas
ABILENE
EL PASO
SAN ANGELO
WACO
AUSTIN
HOUSTON
SAN ANTONIO
CORPUS CHRISTI
BROWNSVILLE
INCHES
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
Over 50

Figure 3. DISTRIBUTION OF ANNUAL PRECIPITATION IN TEXAS

Surface Water

Texas has 15 major river basins and eight coastal basins which add up to more than 80,000 river miles of main streams and tributaries. Streamflow in these river basins varies widely as does the precipitation rate. The average annual historical runoff of all Texas rivers is approximately 42.0 million acre-feet (1941-70).* Runoff decreases from about 1,100 acre-feet per square mile at the eastern boundary of the state to practically zero in large areas of extreme West Texas. Approximately three-fourths of the total runoff occurs in the eastern fourth of the state.

Runoff varies sharply, not only as a function of geography but of time. The annual runoff varies from about 10 million acre-feet during a drought year to more than 96 million acre-feet during a year of excessive rainfall. The average annual runoff between 1940 and 1950 was about 57.0 million acre-feet; during the drought between 1950 and 1956, the average was about 23.0 million.

In consideration of the comprehensive development of Texas resources, another important factor is that more than six million acre-feet of Texas runoff originates on the flat coastal plain where desirable reservoir sites do not exist, making it economically infeasible to store and conserve the water yield. Most of this water will always be discharged into the Gulf.

Traditional development of surface water has taken place during the past 50 years through construction of more than 100 major storage reservoirs and thousands of small reservoirs and farm ponds. Today, possible conservation storage in existing major reservoirs and in those under construction is estimated at over 30 million acre-feet. However, the dependable supply of these reservoirs totals only slightly in excess of about 10.0 million acre-feet in the critical drought period based on individual reservoir firm yield analyses. In 1974, surface water sources supplied approximately 30 percent of the water utilities in the state. (See Table 1.)

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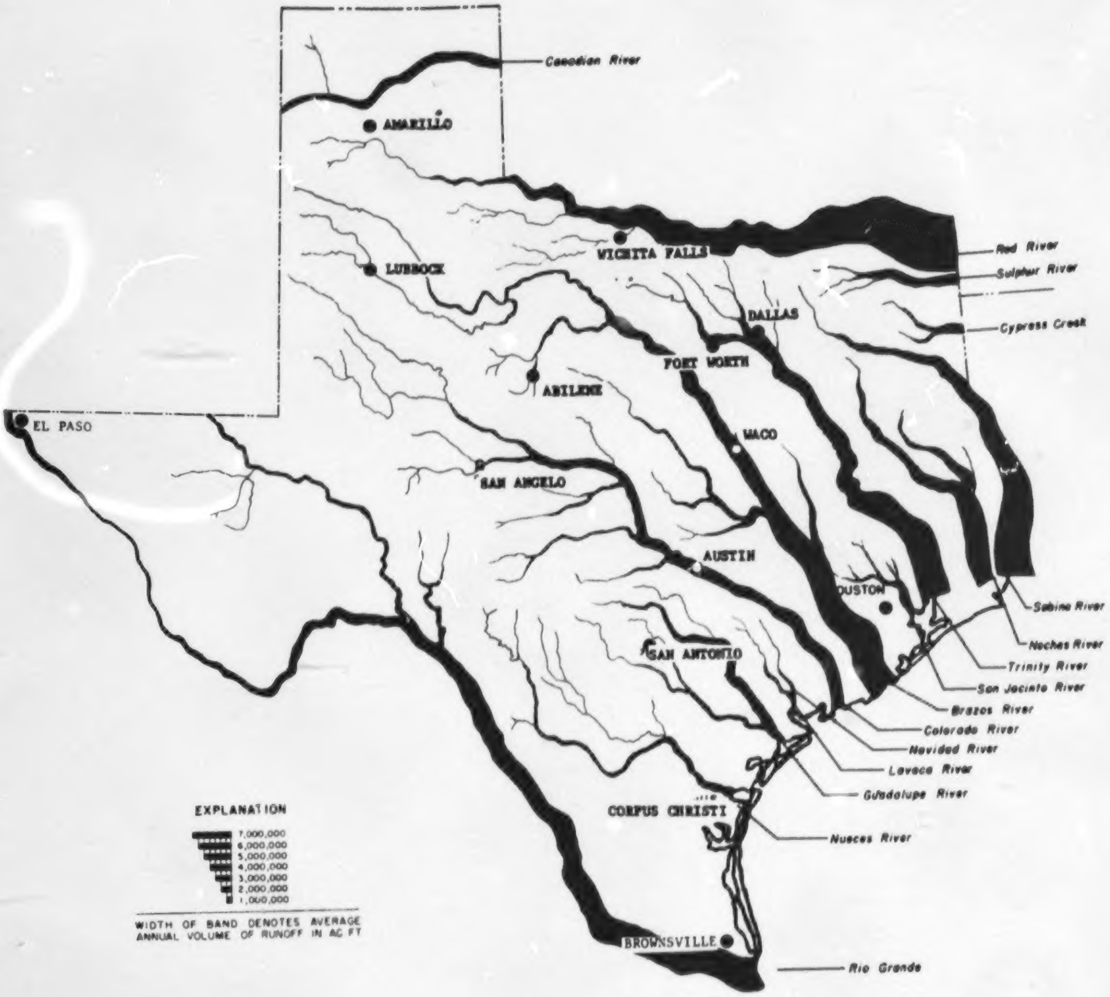
*An acre-foot of water is 325,851 gallons, or one acre of land (43,560 square feet) covered by one foot of water.



Canadian River
AMARILLO
LUBBOCK
WICHITA FALLS
Red River
Sulphur River
Cypress Creek
DALLAS
FORT WORTH
ABILENE
EL PASO
WACO
SAN ANGELO
AUSTIN
HOUSTON
SAN ANTONIO
Sabine River
Neches River
Trinity River
San Jacinto River
Brazos River
Colorado River
Navidad River
Lavaca River
Guadalupe River
CORPUS CHRISTI
Nueces River
BROWNSVILLE
Rio Grande
EXPLANATION
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
WIDTH OF BAND DENOTES AVERAGE ANNUAL VOLUME OF RUNOFF IN AC FT

INTERSTATE STREAMS

Stream	Average Runoff (Acre-Feet)
Canadian River	417,300
Red River	9,818,000
Sulphur River	2,087,500
Cypress Creek	1,581,500
Sabine River	6,438,600
Rio Grande	3,998,700
Subtotal	24,341,600

INTRASTATE STREAMS

Neches River	5,754,400
Trinity River	5,421,200
San Jacinto River	1,888,600
Brazos River	6,445,200
Colorado River	2,452,100
Navidad River	602,300
Lavaca River	
Guadalupe River	1,433,000
Nueces River	640,800
Minor Coastal Areas	3,084,200
Subtotal	27,721,800
TOTAL ALL STREAMS	51,063,400

Figure 4. AVERAGE ANNUAL RUNOFF OF TEXAS STREAMS

Table 1. ESTIMATED 1974 WATER USE IN ACRE-FEET*

Purpose	Ground Water	Surface Water	Total
Municipal	966,300	965,100	1,931,400
Manufacturing	486,400	1,112,700	1,599,100
Steam-Electric Power	51,500	149,400	201,000
Irrigation	10,404,000	2,681,000	13,085,200
Mining	178,900	48,200	227,100
Livestock	124,900	171,500	296,400
TOTAL	12,213,700	5,129,200	17,342,900

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*About 78 percent (13,467,300 acre-feet) of the total water withdrawn was used as shown above. Other uses such as hydroelectric power generation and recreation are not included.

Ground Water

Approximately 70 percent of all water utilized in Texas for municipal, industrial, and irrigation purposes comes from underground sources. Texas in fact is the second largest user of underground water in the United States, surpassed only by California. In many portions of Texas, ground water is present in sufficient quantities to satisfy water demands of minor magnitude on virtually a permanent basis. These demands generally include the requirements for smaller towns, small industries, livestock water, and homestead needs.

Several areas of the state are served by major underground reservoirs, or aquifers. The Ogallala aquifer supplies vast quantities of ground water to the High Plains area: the Gulf Coast aquifer supplies large quantities of ground water along the Texas Coastal Plains; the Edwards limestone aquifer supplies substantial quantities of ground water to San Antonio and the adjacent areas; the Carrizo-Wilcox aquifer supplies water to the area extending from the Rio Grande through South Central and Central Texas to Northeast Texas; and the Trinity group aquifer supplies water to the central part of the Brazos, the upper Trinity River basin, and the lower part of the Red River basin. In addition, there are several alluvial ground water reservoirs in the lower valleys of the Trinity, Brazos, Colorado, and Rio Grande Rivers; terrace deposits in Knox, Haskell, Foard, Wilbarger, and Hardeman Counties; and largely unconsolidated fill in structural troughs in the Trans-Pecos region. Undoubtedly these aquifers will continue to supply some ground water in the future. It must be recognized, however, that constant large-scale demands cannot generally be supplied on a permanent basis from ground water resources. Whenever local and regional demands exceed the recharge rate of the ground water reservoir, the demand is generally met at the expense of a declining water table and a depletion of available supply. This has already been experienced by numerous municipalities and by virtually every major irrigated area in the state relying upon ground water as a primary source of supply.

Ground water supplies are limited and will be depleted when the demands exceed the replacement rate. Hydrologic data on the ground water resources of the state are limited. When there is limited amount of information, it is difficult to safely undertake water development projects. Investigations to obtain such information are conducted by the Texas Department of Water Resources in cooperation with the U.S. Geological Survey and other state, federal, and local agencies.

PLANNING AND DEVELOPMENTAL AGENCIES

State

Water control and conservation projects in the state are the responsibility of a number of administrative and financing agencies that have been established under state laws to meet localized needs. The agencies were established more or less to fit the water problem under consideration at the time. As a result, different classifications and types of agencies now exist in the state. In some areas, they overlap in both jurisdiction and responsibilities. In the public interest, the Texas Department of Water Resources reviews and assists in coordinating all plans for proposed projects and all master plans for water development within the state. The Department also maintains a continuing inventory of water development in the state. Actions affecting water development are coordinated through the Texas Water Development Board and the Texas Water Commission.

Texas' first water agency, the Board of Water Engineers, was created by the Legislature in 1913 to regulate the use of the water in the state's rivers and streams and was the state's only water agency for 44 years.

Then, in 1957, the Texas Legislature took two important steps. First, it created the Texas Water Development Board contingent upon approval by the voters of a constitutional amendment authorizing a $200 million Water Development Fund to provide loans for water development projects. The amendment passed, and until 1965, management of the Water Development Fund was the principal activity of the Water Development Board. Second, the Legislature established a planning division within the Board of Water Engineers that subsequently prepared an inventory of the quantity and quality of the state's water resources.

In 1961, the Board of Water Engineers published the first plan detailing statewide water requirements to the year 1980 and proposed construction of reservoirs in various river basins in the state.

That same year, the Texas Water Pollution Control Board was created. It replaced a former body, the Texas Water Pollution Control Advisory Council. Some significant strides were made on behalf of water quality. Although neither the Council nor the Board had funding or staffing, both worked within the State Department of Health.

The year 1961 saw the state with three Boards dealing with various aspects of water management: the Board of Water Engineers, the Water Development Board, and the Water Pollution Control Board.

In 1962, the Texas Constitution was again amended. The Water Development Board was authorized, in the name of the state, to acquire conservation storage space in reservoirs to be constructed on Texas streams. This provided for the optimum development (in size and capacity) of the limited number of dam and reservoir sites in the state.

In 1965, the Texas Water Commission became the Texas Water Rights Commission. The Water Development Board was assigned duties in addition to administration of the Water Development Fund and became the water resources planning and development agency for the state.

In 1966, another amendment to the Constitution was approved increasing the $200 million Water Development Fund to $400 million. Use of the Fund was expanded to include construction of any system of works necessary for the filtration, treatment, and transportation of water storage to points of wholesale purchase and distribution. This new authority assured the state's participation in the full development of its water resources for the benefit of all sections of Texas.

In 1967, the Legislature passed the Texas Water Quality Act creating the Texas Water Quality Board as a separate state agency with funding and staffing of its own. The Water Pollution Control Board was abolished.

In 1968, the Texas Water Development Board presented the Texas Water Plan as a flexible guide to the development, conservation, and use of the state's water resources to the year 2020. Today, this plan continues to serve as the official guide to state policy for water development in Texas.

The Texas Water Development Board learned early in its planning that Texas, with its growing cities and industries and its thriving irrigated agriculture, does not have enough dependable water supplies within its own boundaries to meet its increasing water requirements beyond the 1990-2000 decade. To meet this projected deficit, the Texas Water Plan provided for the importation of 12 to 13 million acre-feet of water annually from out-of-state sources.

The Texas Water Plan proposed the construction of 67 dams and reservoirs including some alternatives, pipelines and canals, pumping stations, and power plants to move the massive quantities of water needed to meet the state's increasing water requirements.

The Plan is designed to provide multiple benefits for all sections of the state. It provides for the maintenance of the state's important irrigated agriculture; it provides for the preservation of the state's important bay and estuary systems; and it provides recreational benefits for Texas' growing population.

From 1967 until 1977, the Water Development Board, Water Quality Board, and the Water Rights Commission administered the water affairs for the state, each with distinct responsibilities as the names indicate.

In 1977, the Legislature combined the functions of the three water agencies, creating the Texas Department of Water Resources. The legislation provided that the former six-member citizen Water Development Board continue as the Board for the new agency. The Water Quality Board was dissolved, and the Water Rights Commission was abolished to be replaced by the Texas Water Commission which was structured to carry out the judicial functions for the Department. Within the new Department of Water Resources now rest a multitude of responsibilities that serve to develop water resources in Texas, to maintain the quality of the water, and to assure equitable water rights to all Texans.

Federal

Congress has delegated to certain federal agencies responsibilities for various phases of national water-resource development. The federal agencies primarily concerned with the control and development of water resources are: the Corps of Engineers, Department of the Army; Water and Power Resources Administration (formerly the Bureau of Reclamation); Department of the Interior; and the International Boundary and Water Commission, United States Section, an agency of the Department of State. Because of the varied problems involved in water resource development, additional federal agencies participate, either in collaboration or as consultants, in the investigation and planning undertaken by the other federal agencies. Included in this group are the Soil Conservation Service, Department of Agriculture; Federal Energy Regulatory Commission; Fish and Wildlife Service; National Marine Fisheries Service; Forest Service; Geological Survey; Bureau of Indian Affairs; National Parks Service; Public Health Service; and National Weather Service.

WATER QUALITY CONTROL

Control of water pollution in Texas has been a matter of concern to state governmental leaders since 1860 when a water pollution prohibition appeared in the State Penal Code. Fifty-three years later, in 1913, the first general water pollution control law appeared in the Civil Statutes. Early laws, however, were general in nature and held only that waste discharges should not materially affect the quality of the water in a receiving stream. Jurisdiction for enforcement was vested in the Texas State Health Department and the Game and Fish Commission. Population of the state in those earlier years was largely rural so that water pollution problems were slight.

Through the efforts of the Texas Water Quality Board, from 1967 to 1977, the load of pollutants to the state's waters was reduced by 75 percent. In 1977, the Water Quality Board was merged by legislation with other agencies into the Department of Water Resources and water quality management programs are continuing.

Natural pollution has existed in parts of Texas for centuries from salt water springs and from the flow of streams over gypsum-bearing formations. These problems have been studied, and in some places water has been diverted to improve the quality of some of the state's major streams. To further protect and improve the state's water resources, the Texas Railroad Commission prohibits the use of salt water disposal pits for storage of oil field brines, with local exceptions granted on a case-by-case basis.

People are the source of water pollution with the exception of those areas where natural pollution occurs. Where there is a large concentration of people, there generally is water pollution nearby. Three major sources of pollution can be listed: industry, municipalities, and agriculture.

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Wastes from industry, unless properly treated, can cause major pollution problems. Industrial wastes are quite varied in nature and may range from oil and chemical pollutants to thermal pollution caused by heated water discharges from cooling systems. Although pollution abatement by industry is generally of a more complex nature than treatment of municipal waste, industrial pollution can be prevented or controlled through waste treatment processes or process changes within the industry.

Many municipalities do not have adequate sewage treatment facilities to treat the volume of domestic waste that reaches the treatment plant. Although domestic sewage is 99.9 percent water, it still can create a major pollution problem if the 0.1 percent solids are not removed. If the treatment plant is not of adequate size to handle the wastes or is not properly managed and operated, these wastes find their way into the surface waters of the state. Another major source of waste coming from municipalities is storm water or rain runoff from yards, service station drives, and streets which eventually finds its way into the surface waters. This runoff water is extremely high in dissolved and suspended solids and contributes to pollution problems.

Pollution resulting from rainfall runoff from municipal sites, agricultural land, and construction sites is referred to as pollution from nonpoint sources.

Agriculture has become another major contributor of pollutants. Soil erosion; wastes from feed lots; improper or excessive use of pesticides, herbicides, and fertilizers; and the careless discharge of trash and junk are a few of the pollutants in the agricultural category. Farmers can help prevent or reduce water pollution by impounding or diverting waste waters, by properly applying agricultural chemicals and fertilizers, and by good soil conservation practices.

Although heavy metals (such as mercury), pesticides, and toxic chemicals are specific pollutants that cause grave consequences, organic waste that may be produced by municipalities, industry, or agriculture is of most concern. A lake or a stream has what is referred to as assimilative capacity. This means that the water has the ability to cleanse itself through the action of bacteria, algae, plants, and the addition of oxygen. Minute amounts of organic matter may be assimilated by the waters. However, when overloaded with organics, oxygen in the water is used up, resulting in many undesirable conditions, one of which is the death of fish.

Although water quality management is a major undertaking, the Texas Department of Water Resources, the state's water pollution control agency, continues an active pollution abatement program at this time. The waters in the state continue to be subjected to extensive use and reuse from the steadily increasing population and from growing industrial and recreational endeavors. Therefore, to improve and maintain good water quality in the state, it is essential to have the continued interest and support of individual citizens.

PRIORITIES FOR USE OF WATER

The use of the state's waters is determined by the Texas Water Commission. Texas law declares that all waters of the state—except underground water—belong to the people of Texas and that any use of the waters must be determined by the state.

The people of Texas, through legislation, have established priorities for the use of water: (1) homes and municipalities; (2) industries; (3) irrigation; (4) mining; (5) production of hydroelectric power; (6) navigation; and (7) recreation. These priorities provide a basis for Texas Water Commission decisions on the use of the state's water resources.

River authorities, established by the state at the request of interests within each river basin, are active in planning orderly development of water-control and conservation facilities in their areas. In addition to major projects, these authorities assist in developing treatment of local supply and quality water works for areas that could not carry the load alone.

In compliance with constitutional provisions, the Legislature has made statutory provisions for the creation of the following types of water districts:

Water Improvement District
Water Control and Improvement District
Water Control and Preservation District
Fresh Water Supply District
Municipal Utility District
Levee Improvement District
Drainage District
Conservation and Reclamation District
Navigation District
Underground Water Conservation District
Multi-City District

In addition to those established under general law, special authorities and districts created by the Legislature include river authorities, valley authorities, sanitation authorities, water and soil conservation authorities, municipal water supply districts, water recreational districts, water supply districts, flood control districts, conservation districts, navigation and port districts, and water and sewer improvement districts.

STATE AND NATIONAL ECONOMY

Changes in State and National Conditions in 1940s

In 1940, Texas was primarily a producer of raw materials that were processed into finished products elsewhere in the United States. Petroleum refining was the state's only major manufacturing industry. About one million acres in Texas were under irrigation, and Texas ranked eighth among the states in irrigated area. Approximately 60 percent of the state's population lived in rural areas or small communities.

During World War II and postwar years, there was a tremendous upsurge in national population accompanied by even more spectacular increases in national agricultural and industrial productivity and consumption. The state's population has continued to follow the early postwar pattern of growth. In 1970, Texas' population exceeded 11.1 million—and all indications point to a 1980 population in excess of 13 million. Texas has become the nation's third most populous state.

The combination of national population growth and increased per capita consumption has continuously enlarged the national market for all products, which has resulted in marked increases in agricultural and industrial production. Texas farmers and agribusiness interests have capitalized on new markets for agricultural products by increasing the state's irrigated area to 8.6 million acres. Large-scale industrialization has occurred principally along the Gulf Coast, in the Dallas-Fort Worth area, and in the Amarillo-Lubbock area.

Texas today is first in the nation in value of minerals produced, and the state's economy has been broadened by the vast expansion of the petroleum products industry. The production of petrochemical products has become the fastest growing of all Texas' industries. In 1975, the state was estimated to have 31.1 percent of the proved natural gas reserves and 32.6 percent of the total liquid hydrocarbon reserves in the nation.

The scale of manufacturing in Texas has increased rapidly. In 1949, the value to the economy added by manufacturing was $1.8 billion; in 1972, $15.3 billion. Recent broad-based industrial development in Texas has also demanded the rapid expansion of trades and services in the past 10 years to support employees as well as plants. Retail trade, wholesale trade, and selected service sales, which in 1958 totalled more than $26.5 billion and employed more than 738,000, had sales of almost $74 billion and employed nearly 1,200,000 by 1972. This new industrial development has been a major factor in transforming the character of Texas society from predominantly rural to urban.

Increase in Water Usage Since 1940

Municipal, industrial, and irrigation expansion in the state since 1940 has been accompanied by a major increase in municipal, industrial, and irrigation water usage. In 1940, Texas was using water for these purposes at the rate of about three million acre-feet a year, of which irrigation accounted for about 2.5 million acre-feet, or more than 80 percent. Industrial water use, primarily for petroleum refining, exceeded 100,000 acre-feet annually. Municipal water usage, including the water requirements of other industries, was about 400,000 acre-feet annually. In 1979, the annual water usage in Texas was in excess of 17.3 million acre-feet. Again irrigation use was about 75 percent of the total, amounting to over 13 million acre-feet per year. Water use by the large industries in 1979 was about 1.6 million acre-feet annually, the increase resulting primarily from expansion of petroleum refining and the establishment and growth of the petrochemical industry. At the end of the 70s, municipal water usage was about 1.9 million acre-feet annually.

Much of the increase in water usage since 1940 has been in increased utilization of ground water, which in '79 supplied about 12.2 million acre-feet annually, of which about 85 percent was used by agriculture.

Significant increases in water use and the simultaneous expansion of Texas cities, industries, and irrigation have been made possible by a major expansion of municipal, industrial, and irrigation water-supply facilities. Much of the current Texas water usage, however, is being obtained at rates in excess of the dependable supply. Where this situation prevails and unused water resources are available, new supplies must be developed to meet water requirements, if the state's economic development is to be maintained.

Cypress Dam and Reservoir is a flood control and water supply reservoir.

Outlook for the Future

A large percentage of major industries in Texas are highly water intensive; that is, they use large quantities of water to process various natural resources into industrial products. As a consequence, provision of adequate economical and industrial water supplies of acceptable quality is essential to full development and utilization of natural resources and corresponding economic stability and growth. New industrial development induces additional population growth. This growth increases water needs for domestic and other municipal purposes. Therefore, full development and utilization of Texas resources to sustain industrial growth and a stable economy will necessitate development of additional water supplies.

In the future, irrigation will continue to be a valuable aid in increasing Texas farm production and income. The 8.6 million acres now irrigated is about 6 percent of the total land in farms in the state and about 40 percent of the harvested cropland. This irrigated area produces about 30 percent of the state's agricultural income and more than 60 percent of the income from harvested crops.

A substantial proportion of the present ground water supplies used for irrigation may ultimately be exhausted if pumping at current rates continue. In addition, if present high energy costs prevail, the expense of pumping water from deeper depths may make the cost of producing irrigation water prohibitive for crop production.

To offset the predicted adverse production and income effect of declining supplies of ground water, new and dependable supplies should be developed from presently unused water resources in the state as well as outside the boundaries of Texas. These new developments would assist in offsetting the decline in the state's irrigated agricultural and agribusiness income which may result from eventual exhaustion of ground water supplies.

Economic and political considerations present complex problems in development of new water supplies for Texas. These problems relate first to the magnitude of the new supplies that should be developed and second to the problem of financing the cost of such development.

National Interest

Solution of the water supply problems of Texas is a matter of national concern. Texas possesses a large share of several of the nation's most essential resources, and the products obtainable from those resources will continue to be needed to supply national requirements for civilian consumption and national defense. In the national interest, new water supplies must be created wherever they are needed and can be developed to assure that production will not be retarded or prevented by lack of water. In those cases where development of needed new water supplies cannot be undertaken either by local interests or by agencies of the State of Texas, the national interest may justify federal financial and other assistance.

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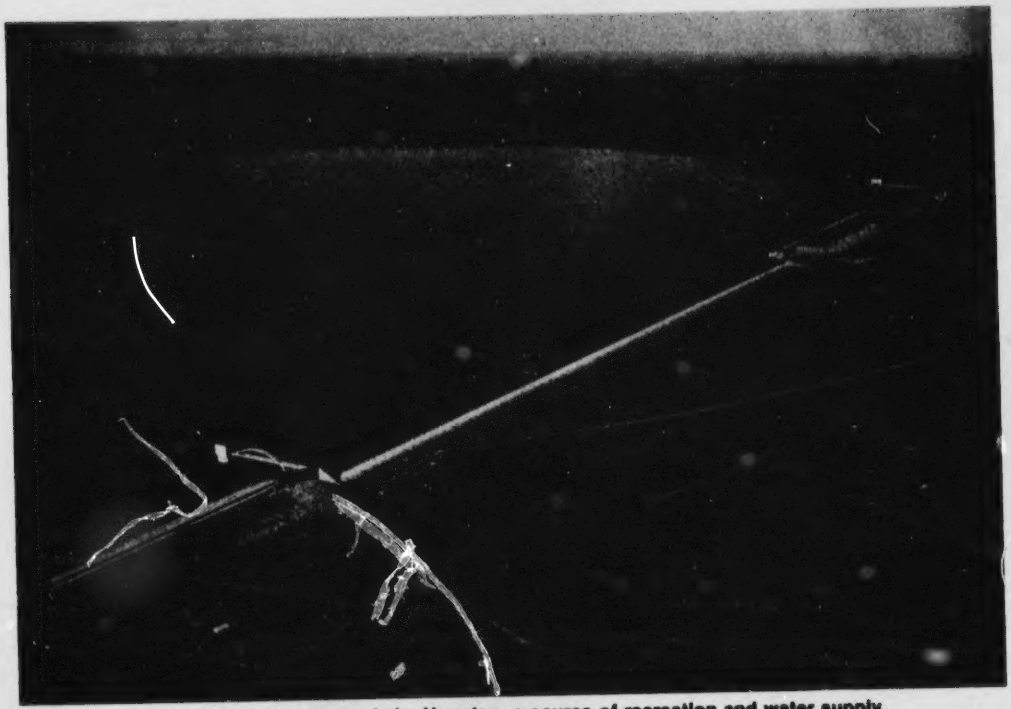
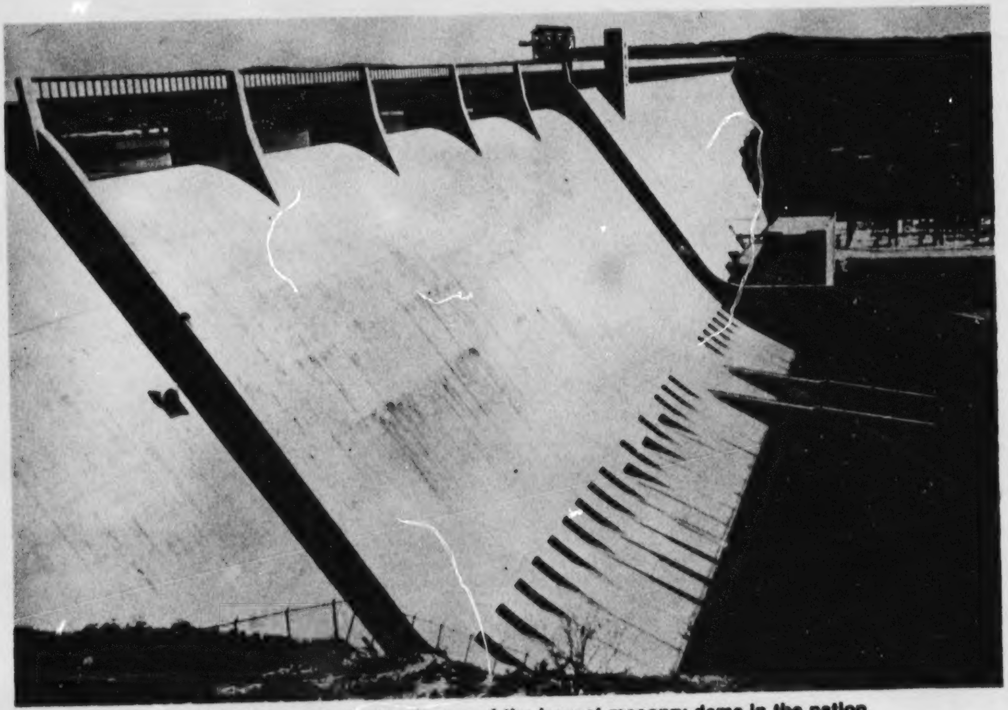


San Jacinto Dam forms Lake Houston, a source of recreation and water supply.



Mansfield Dam, near Austin, is one of the largest masonry dams in the nation.

Estuarine Resources of Texas

An estuary, or bay, is "a semi-enclosed coastal body of water having a free connection with the open sea and within which the sea water is measurably diluted with fresh water deriving from land drainage."*

Estuaries are recognized as the most highly productive areas on Earth from the standpoint of biological production. They are the farms or food sources for aquatic life just as farmlands are the sources that provide food for humans. In the estuaries of North America, the production of plant materials is estimated to be six times greater than that of the best cultivated crops on land. The high production of plant materials enables the estuaries to support large numbers of animals of many species, from bacteria to birds and fish.

GENERAL CHARACTERISTICS

Estuaries vary in their degree of dependence on the production of plants. The production of plants includes single-celled plants called phytoplankton or higher plants in the form of attached algae, seagrasses, or marsh plants. Although each type of plant can usually be found in any estuary, one type usually dominates the others in a particular estuary and thus forms the major source of the primary production in that system.

The Gulf shoreline of Texas, extending 370 miles from the Louisiana border to the Rio Grande River, is comprised of eight major estuarine systems (Figure 1). These estuaries, covering 2,394 square miles, vary in relation to the amount of freshwater runoff received and the source of primary production. Estuaries on the upper coast (Sabine Lake, Galveston Bay, Matagorda Bay, and San Antonio Bay) are generally characterized by large marsh complexes that contribute the major portion of primary production to the systems. The marsh complexes on the central coast (Aransas and Corpus Christi Bays) depend upon phytoplankton, seagrass, and algae production. The Laguna Madre is primarily dependent upon seagrass and algae production.

ESTUARINE LIFE

There are approximately 1,783 square miles of marshes and tidal flats (areas which are periodically exposed by low tides) within Texas' estuarine areas. In addition to their function of providing the plant materials used as a food source by the fish and shellfish (shrimp, crabs, and oysters) that inhabit the estuaries, these areas serve to protect the young of many species from excessive predation by larger organisms. Since many species depend upon the shallow marshes and tidal flats for food and protection during their early development, these areas are usually called nurseries.

Although some species (such as oysters) spend their entire lives within the estuaries, most of the fish and shellfish of importance to the sport and commercial saltwater fisheries of Texas move between the open Gulf and the estuaries at various times during their life cycles. The life histories of these species are generally similar to that of the shrimp, illustrated in Figure 2. The adults inhabit the Gulf of Mexico and areas adjacent to the openings (passes) between the Gulf and the estuaries. The adults spawn (lay their eggs) in the open Gulf waters, and the larvae pass through several developmental stages before entering the estuaries through the passes. The post-larvae and juveniles move into the nursery areas of the estuaries where they may take advantage of the

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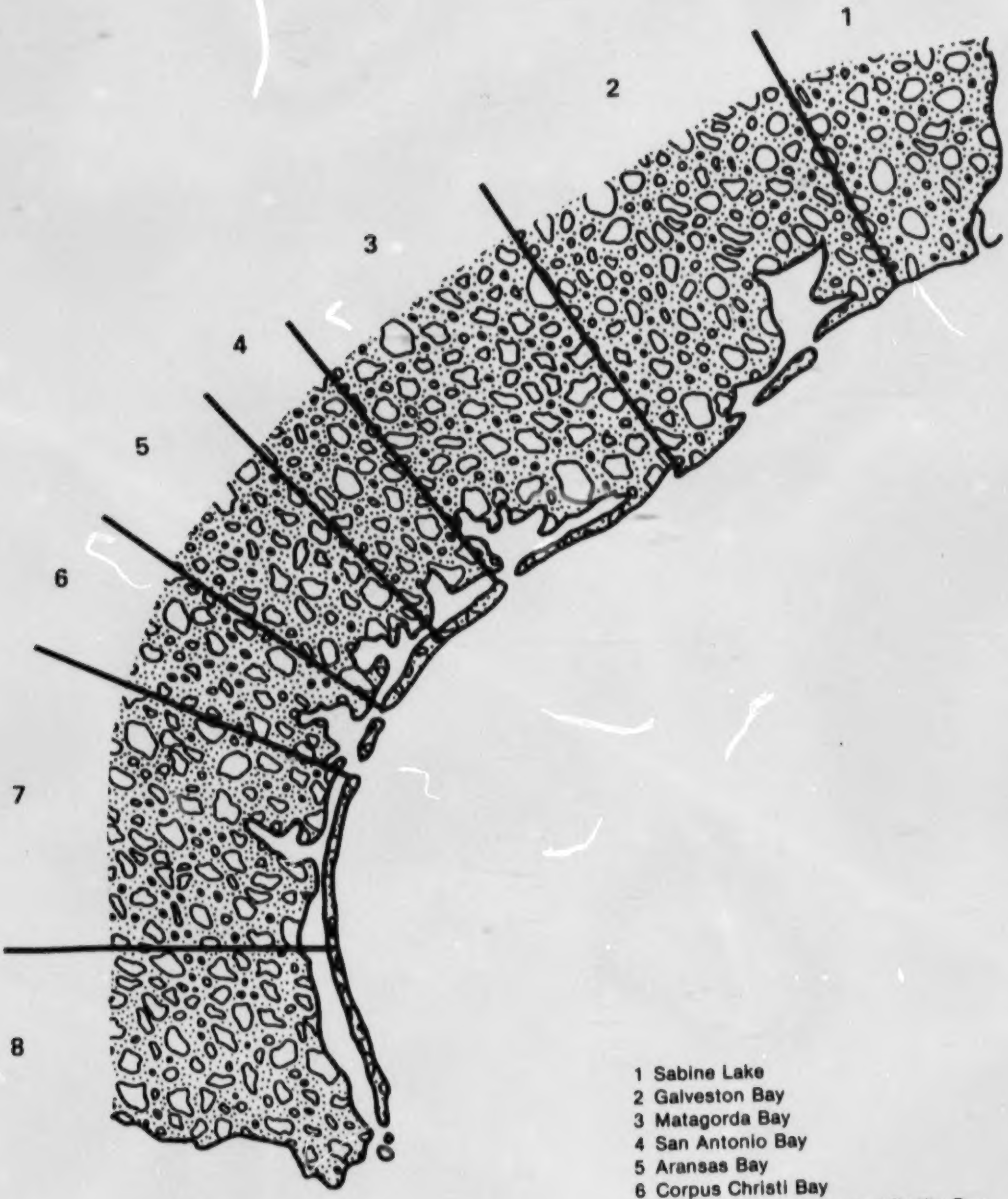
*Cameron, W.M. and D.W. Pritchard. 1963. ***In The Sea.*** Interscience Publishers; John Wiley and Sons; Vol. 2; Chapter 15; Estuaries, pages 306-322.

abundant food supplies and the relative safety from predators. As they grow and mature, the juveniles move out of the shallow nursery areas and into the open estuary. The adults then move from the estuaries into the Gulf to complete the cycle by spawning in their turn.

The most vulnerable phase of this life cycle, which is shared by so many of the important estuarine species, is that portion that is passed by the young within the nursery areas. The amount of nursery area available to these species, and the amount of food materials the areas can produce, is limited. The carrying capacity (the numbers and weight of animals that can be supported) of the nursery areas is subject to great variation from natural causes. The carrying capacity can also be drastically reduced by many human activities if care is not exercised. Unfortunately, most of the injuries committed by people upon these systems are permanent, whereas natural events generally have short-term consequences that are rectified within a few years.

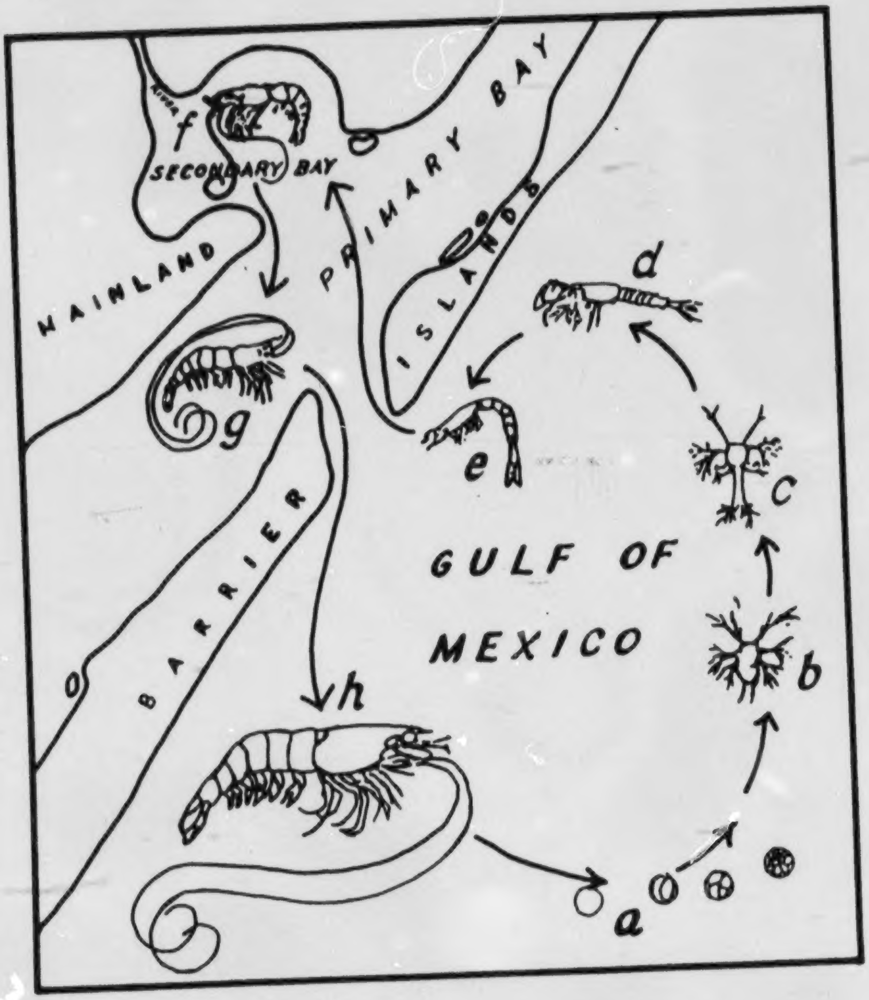
A concern for the future of the nursery areas within the state's estuaries is based on the recognition of their importance to the estuarine species. These species warrant protection because they are of value to those people who depend upon them for recreation, for food, and for jobs.

Through the efforts of conservation agencies, citizens' groups, and seafood processors' organizations, current dangers to estuaries are being brought to public attention. The effects of municipal and industrial pollution, bulkheading, dredging, and filling upon the estuaries are becoming well known, and the public is encouraging public officials to take the necessary steps to ensure the protection of estuaries.



1 Sabine Lake
2 Galveston Bay
3 Matagorda Bay
4 San Antonio Bay
5 Aransas Bay
6 Corpus Christi Bay
7 Upper Laguna Madre and Baffin Bay
8 Lower Laguna Madre

Figure 1. TEXAS ESTUARINE SYSTEM


RIVER
f
SECONDARY BAY
MAINLAND
PRIMARY BAY
ISLANDS
d
g
e
BARRIER
c
GULF OF
MEXICO
b
h
a

- a. Shrimp eggs
- b. Larval stages
- c. Larval stages
- d. Larval stages
- e. Post larvae enter bays
- f. Juveniles grow in estuaries
- g. Sub-adults emigrate to Gulf
- h. Adults spawn

Figure 2. LIFE HISTORY OF SHRIMP

COMPLIANCE STATEMENT

TITLE VI, CIVIL RIGHTS ACT OF 1964; THE MODIFIED COURT ORDER, CIVIL ACTION 5281, FEDERAL DISTRICT COURT, EASTERN DISTRICT OF TEXAS, TYLER DIVISION

Reviews of local education agencies pertaining to compliance with Title VI Civil Rights Act of 1964 and with specific requirements of the Modified Court Order, Civil Action No. 5281, Federal District Court, Eastern District of Texas, Tyler Division are conducted periodically by staff representatives of the Texas Education Agency. These reviews cover at least the following policies and practices:

(1) acceptance policies on student transfers from other school districts;

(2) operation of school bus routes or runs on a non-segregated basis;

(3) nondiscrimination in extracurricular activities and the use of school facilities;

(4) nondiscriminatory practices in the hiring, assigning, promoting, paying, demoting, reassigning, or dismissing of faculty and staff members who work with children;

(5) enrollment and assignment of students without discrimination on the basis of race, color, or national origin;

(6) nondiscriminatory practices relating to the use of a student's first language; and

(7) evidence of published procedures for hearing complaints and grievances.

In addition to conducting reviews, the Texas Education Agency staff representatives check complaints of discrimination made by a citizen or citizens residing in a school district where it is alleged discriminatory practices have occurred or are occurring.

Where a violation of Title VI of the Civil Rights Act is found, the findings are reported to the Office for Civil Rights, Department of Health, Education and Welfare.

If there is a direct violation of the Court Order in Civil Action No. 5281 that cannot be cleared through negotiation, the sanctions required by the Court Order are applied.

TITLE VII, CIVIL RIGHTS ACT OF 1964; EXECUTIVE ORDERS 11246 AND 11375; TITLE IX, 1973 EDUCATION AMENDMENTS; REHABILITATION ACT OF 1973 AS AMENDED; 1974 AMENDMENTS TO THE WAGE-HOUR LAW EXPANDING THE AGE DISCRIMINATION IN EMPLOYMENT ACT OF 1967; AND VIETNAM ERA VETERANS READJUSTMENT ASSISTANCE ACT OF 1972 AS AMENDED IN 1974.

It is the policy of the Texas Education Agency to comply fully with the nondiscrimination provisions of all federal and state laws and regulations by assuring that no person shall be excluded from consideration for recruitment, selection, appointment, training, promotion, retention, or any other personnel action, or be denied any benefits or participation in any programs or activities which it operates on the grounds of race, religion, color, national origin, sex, handicap, age, or veteran status (except where age, sex, or handicap constitute a bona fide occupational qualification necessary to proper and efficient administration). The Texas Education Agency makes positive efforts to employ and advance in employment all protected groups.